October 1997 www.nasatech.com Vol. 21 No. 10

TECH BRIEFS

THE DESIGN/ENGINEERING TECHNOLOGY DIGEST

Sensors/Imaging Special Focus

NASA's Software of the Year

Motion Control Tech Briefs

Laser Tech Briefs

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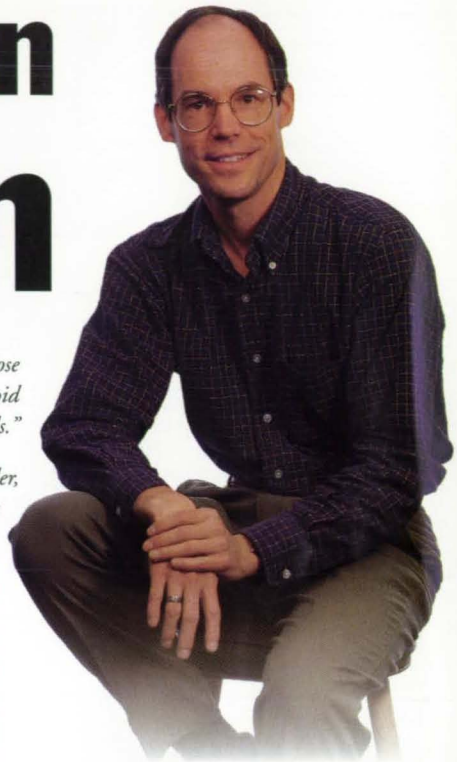

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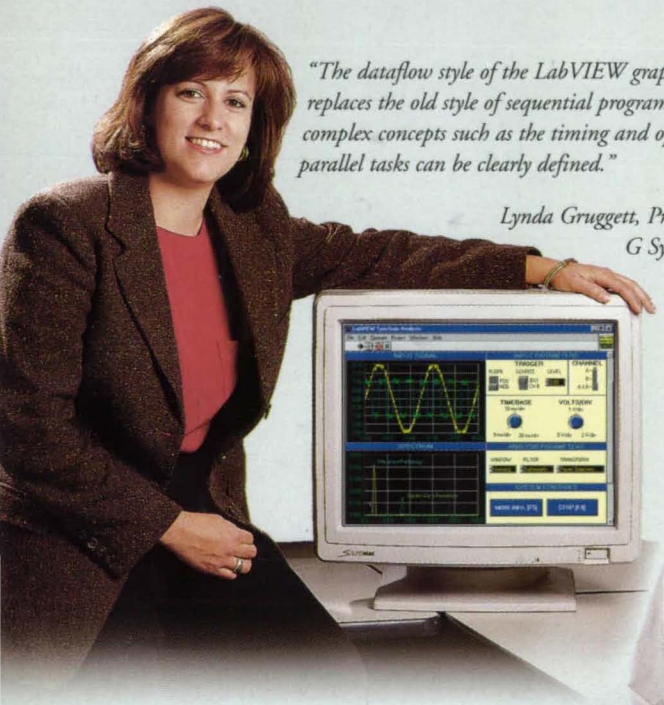
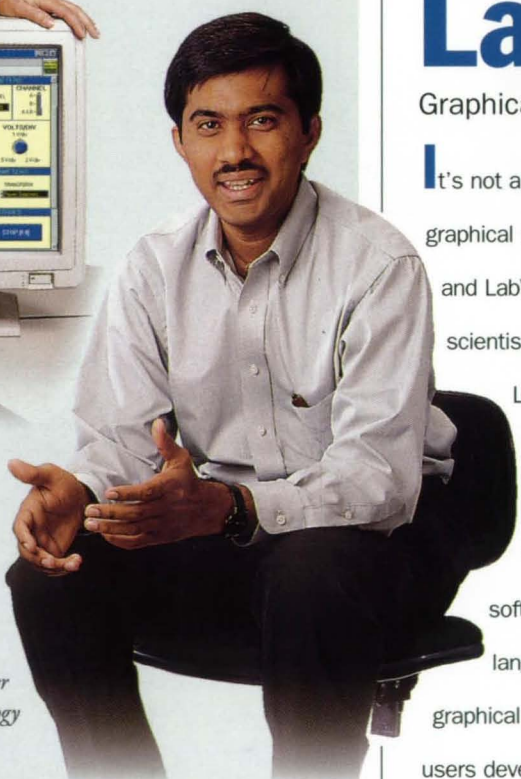
Jim Campbell, Cofounder,
Viewpoint Software Solutions

"The dataflow style of the LabVIEW graphical language replaces the old style of sequential programming – now, complex concepts such as the timing and operation of parallel tasks can be clearly defined."

Lynda Gruggett, President,
G Systems





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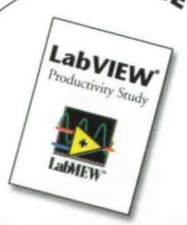

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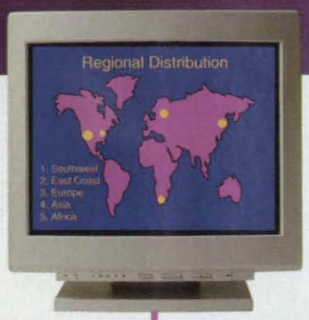

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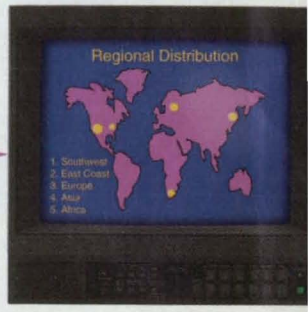

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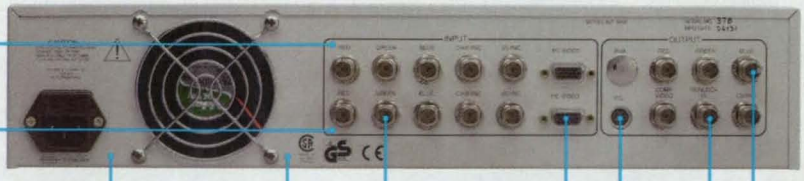

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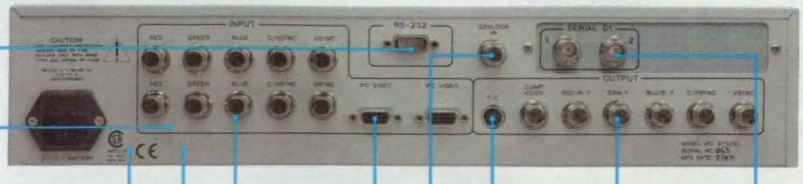

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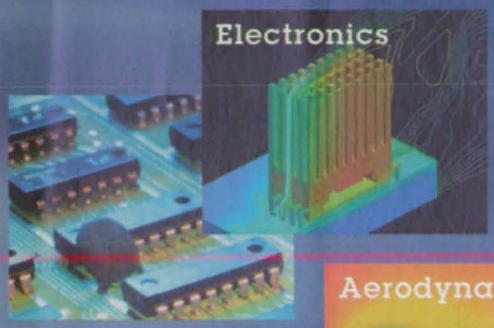

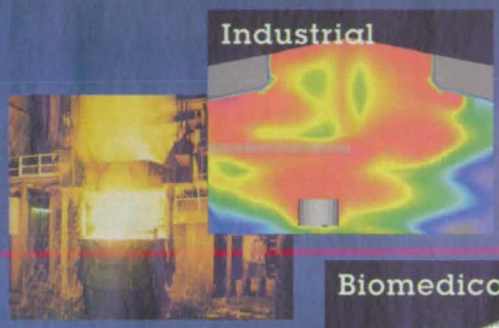

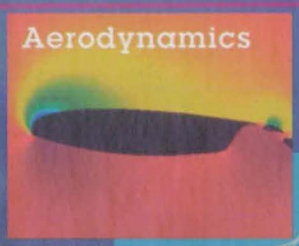

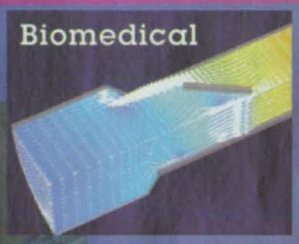

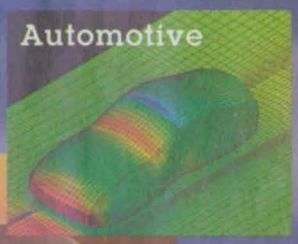

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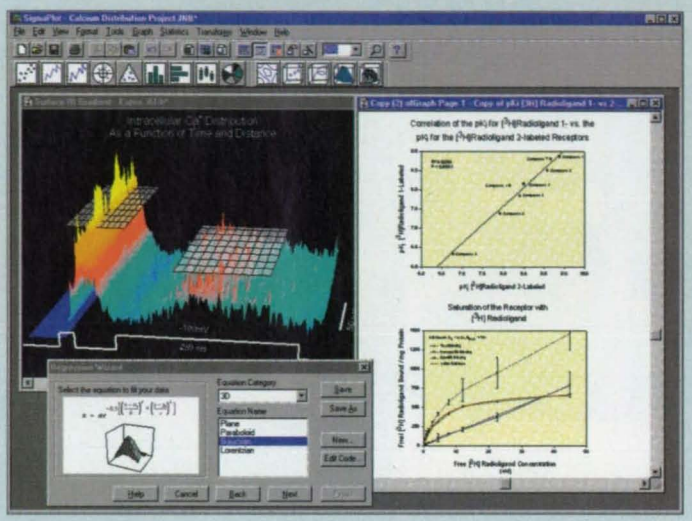
Dr. Barry Simon, Ph.D., *Desktop Engineering Magazine*, September 1996



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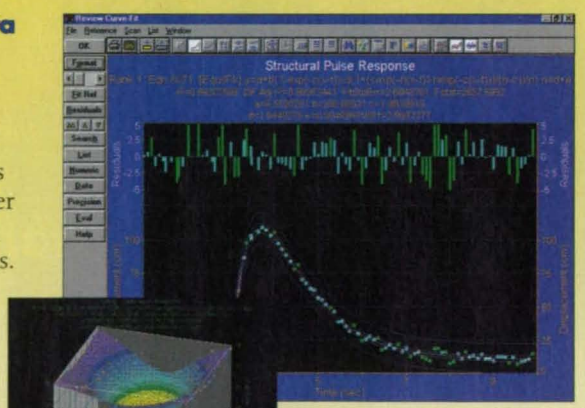

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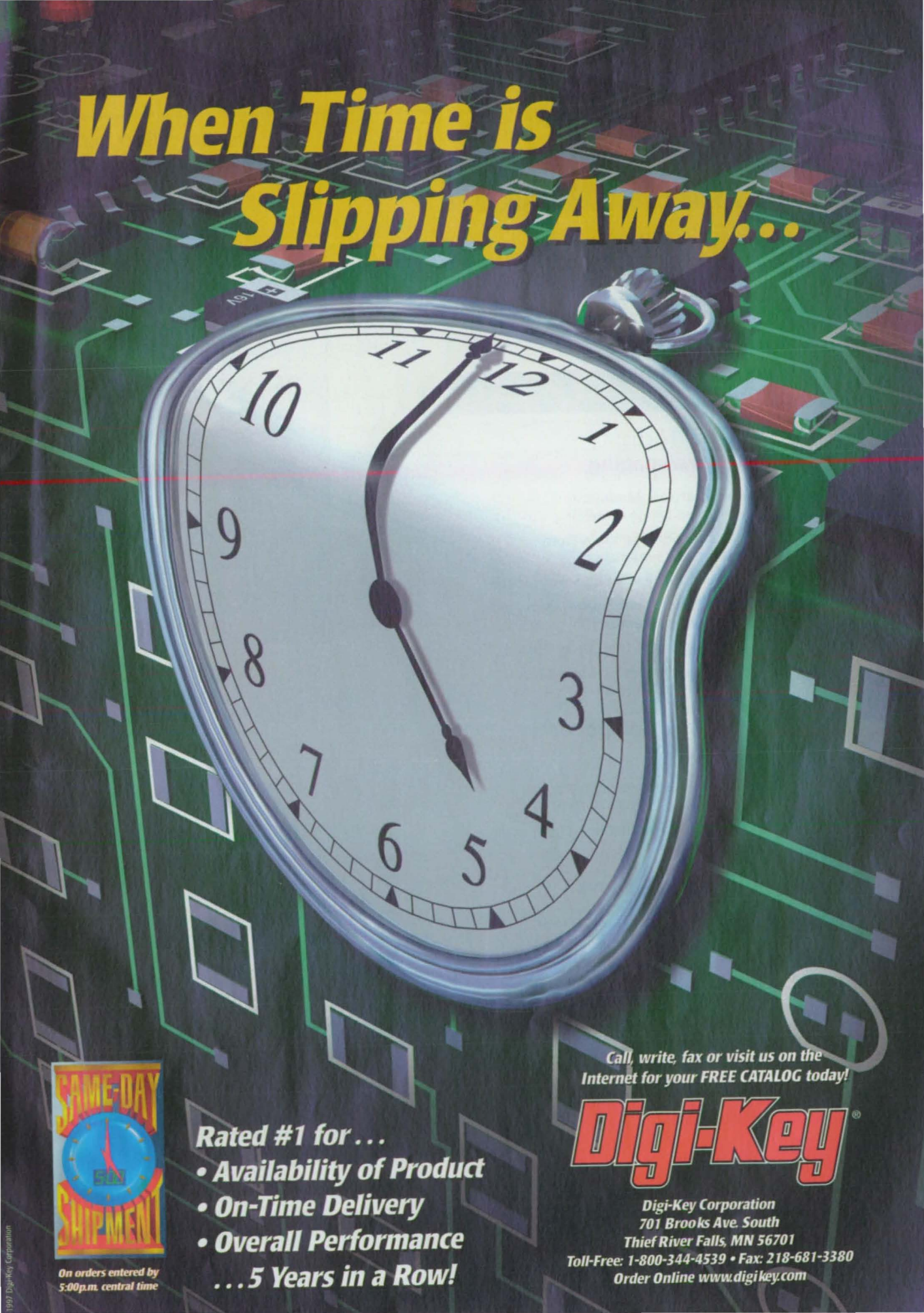
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TECH BRIEFS

October 1997 • Vol.21 No. 10

Features

20 Guest Editorial
Small Business: Vital Link to NASA's Future

22 Application Briefs

70 NASA's Software of the Year

Briefs

26 Special Focus: Sensors/Imaging

26 Neural-Network Modules for High-Speed Image Processing

26 Reconstruction of Images From Circular-Scan Sensors

30 Advanced X-Ray Imaging Spectrometer

30 Digital Video System Images Damaged Gears During Operation

32 Image-Analysis System Tracks Objects

35 Swept-Frequency Fiber-Optic Readout From Multiple Sensors

40 Electronic Components and Circuits

40 GaAs-JFET-Based Multiplexers for Readout of VLWIR Detectors

42 Electronically Switchable Bragg Gratings (ESBGs)

46 Electronic Systems

46 Telerobot Control for Microsurgery

46 Hydrogen-Fire-Detector Calibration Unit

52 Physical Sciences

52 Better Cells for Multiple-Pass Absorption of Light in Gases

56 Optical Air Mass Flux Sensor for Aeroengine Monitoring and Control

58 Electrochemical Process for Treatment of Wastewater

62 Materials

62 Adhesively Bonded Strain Gauges for Temperatures up to 400 °C

64 Modified CVI Process for Making SiC/SiC Composites

65 Unsymmetrical Squaraine Dyes for Nonlinear Optics

Departments

14 Commercial Technology Team

16 NASA Patents

24 Commercialization Opportunities

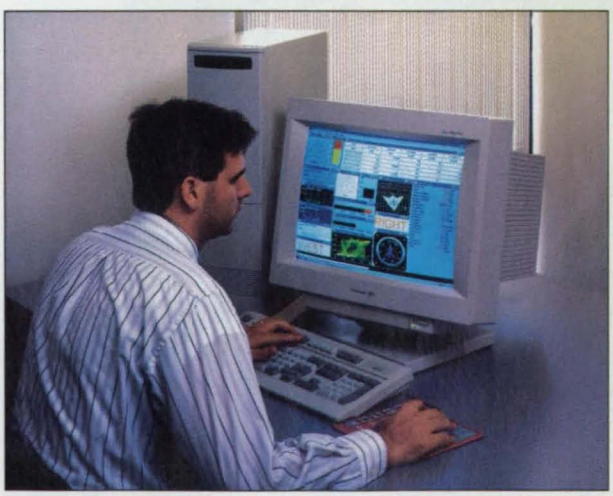
36 Special Focus Products

107 New on Disk

108 New on the Market

110 New Literature

112 Advertisers Index

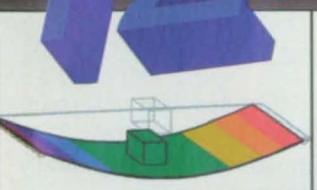


NASA's ground network stations have been re-engineered to reduce life cycle costs for the Space Shuttle. Real-time range safety data in the laboratory and at the launch site will be developed using Visual Test Systems (VTS) data acquisition systems from L3 Communications Telemetry & Instrumentation of San Diego, CA. The customized VTS station shown is one of five to be installed for NASA to keep close track of the shuttle's flight performance. For more information, see Application Briefs on page 22.

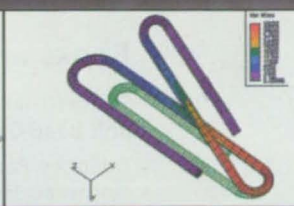
Photo courtesy of L3 Communications

Now: NONLINEAR that's EASY

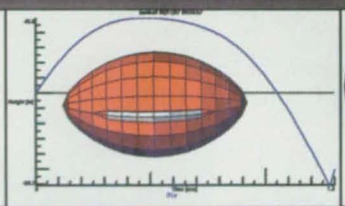
12 EASY things you can do with Nonlinear that you can't do with regular linear stress analysis



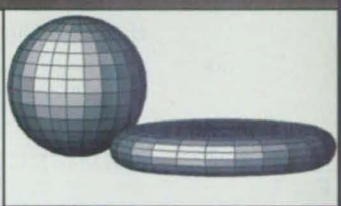
ut of plane bending - Use nonlinear alysis to determine whether this plate ll foreshorten and fall out of its support. near cannot predict geometry changes rpendicular to a load.



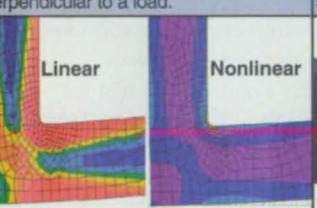
Permanent deformation - Algor's nonlinear analysis can predict the permanent deformation when the predicted stress exceeds the yield stress. Linear analysis can't do this.



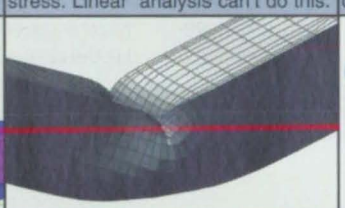
Trajectory - Basic motion, such as the trajectory of this rotating football is easily done using Algor's nonlinear analysis. Linear analysis cannot predict motion.



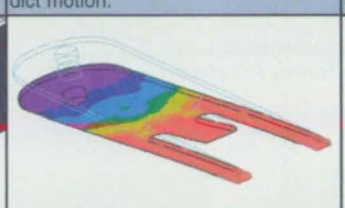
Squashing - Squashing this rubber ball in a vice using linear analysis cannot predict the final shape like this nonlinear analysis.



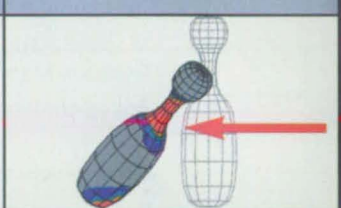
tress concentration - Linear stress alysis will misrepresent both the ress and the deformation of this nger due to minute changes in the et. Nonlinear analysis gets it right.



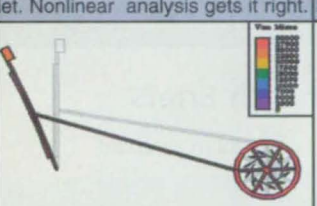
Local buckling - When failure is due to local buckling, the geometry fails at stresses much, much lower than the yield stress. Linear cannot detect local buckling.



Snap-through - Any time you have a snap-through effect, your part is in motion until it stops on the other side. You need nonlinear analysis to predict this effect.

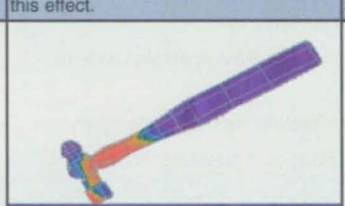


Impact - Nonlinear dynamic response predicts the stress in an object when it goes into motion as a result of impact by another object. Linear analysis cannot analyze for impact and motion.



bar link - Linear dynamic analysis annot predict the forces and stress- s due to periodic loading. ccupak/VE simulates the loading nd stresses in one analysis.

3-D mechanism - When a moving object is a 3-D mechanism, high inertia forces can occur. You need Accupak/VE to predict the stresses caused by motion.



Contact impact - Kinematic motion and the stresses due to the shock of impact cannot be predicted by either linear stress analysis or kinematics analysis software. Accupak/VE does it in one shot..

Elastic large deformation - Nonlinear analysis predicts the stressed geometry when the deformation is significant, even if the material properties remain linear. Linear analysis fails at this.

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Contents *continued*

68 Computer Software

68 The SPICE System

68 Program for Analyzing Flutter of Propfan Blades

68 Computer Program for Emulating MIL-STD-1750a Computer

72 Mechanics

72 Focus-Ring Mechanism Translates Lenses Without Rotation

74 Portable Computer Workstations for Engineering Teams

78 Model-Based Placement of Gearbox-Monitoring Accelerometers

80 Rolled-Up Ramp Deploys Itself on Command

81 Identifying Loose Joints in an Adaptive Truss Structure

84 Machinery/Automation

84 Heat Pump for Quick Warming of Automobile Passenger Space

84 Designing Electrically Powered Actuators for Aircraft

86 Force-Feedback Device for Microsurgery

87 Rotordynamic Seal and Bearing Tester

89 Manufacturing/Fabrication

89 Holographic Lithography With Phase Feedback

90 Soldering Parts Together at Precise Faying Surfaces

91 Soldering Stacked Integrated-Circuit Chips

92 Fabricating and Testing an Ultrathin Mirror

93 Mathematics and Information Sciences

93 Predicting Where Terminated Unpiloted Aircraft Will Land

94 Dynamic Routing for Networks With Random Connectivities

96 Life Sciences

96 Continuous Unidirectional Locking Orthotic Joint

98 Books and Reports

98 Factors That Affect Readings of Ultrasonic Bolt-Load Gauges

98 Adaptive Footpads With Pyrotechnically Anchored Tethers

99 High-Temperature Fatigue Testing of PMCs

99 More About a Laser-Speckle Surface-Strain Gauge

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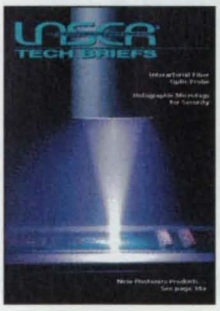

Laser Tech Briefs

Follows page 88 in selected editions only.

Motion Control Tech Briefs

Follows page 96 in selected editions only.

On the cover:

Advances in sensors — as well as image acquisition, processing, and analysis — are featured in this month's Special Focus, which begins on page 26. Among the Sensors/Imaging products described are these Hall Effect geartooth sensor modules from Cherry Electrical Products, Waukegan, IL, that are manufactured using a patent-pending process to individually tune each sensor.

Photo courtesy of Cherry Electrical Products

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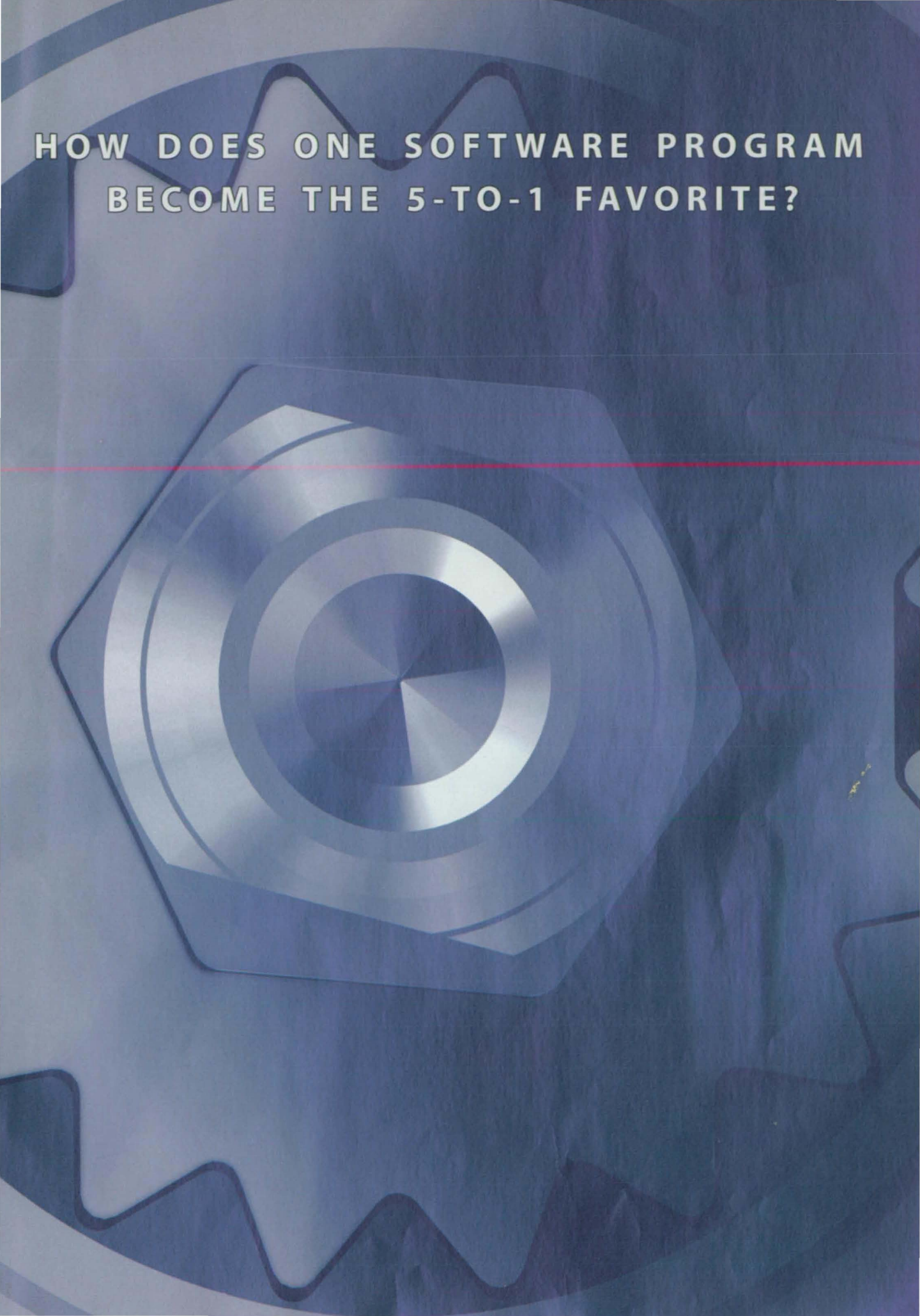
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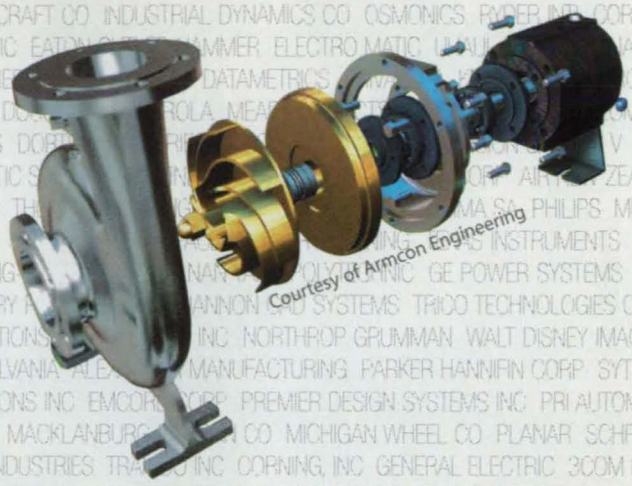

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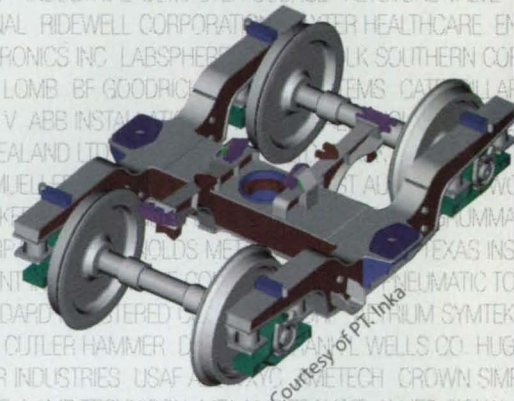

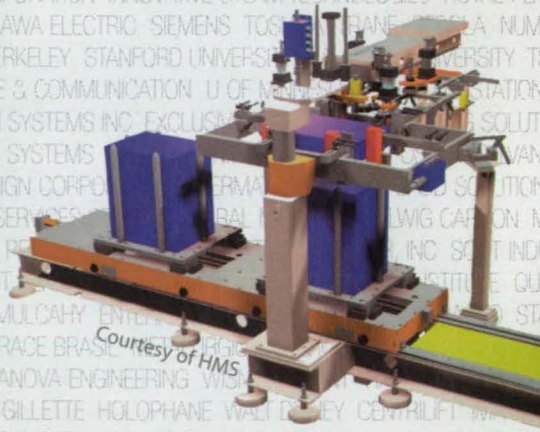

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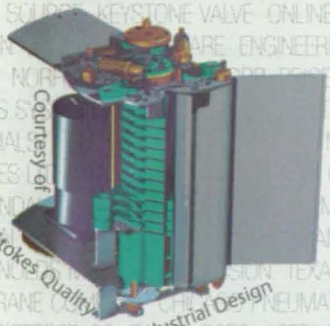

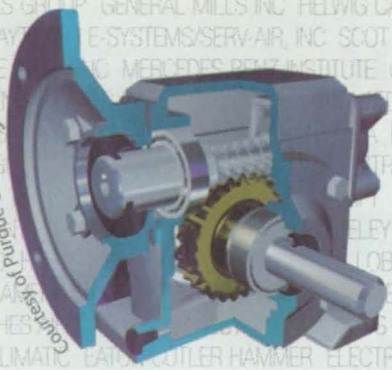

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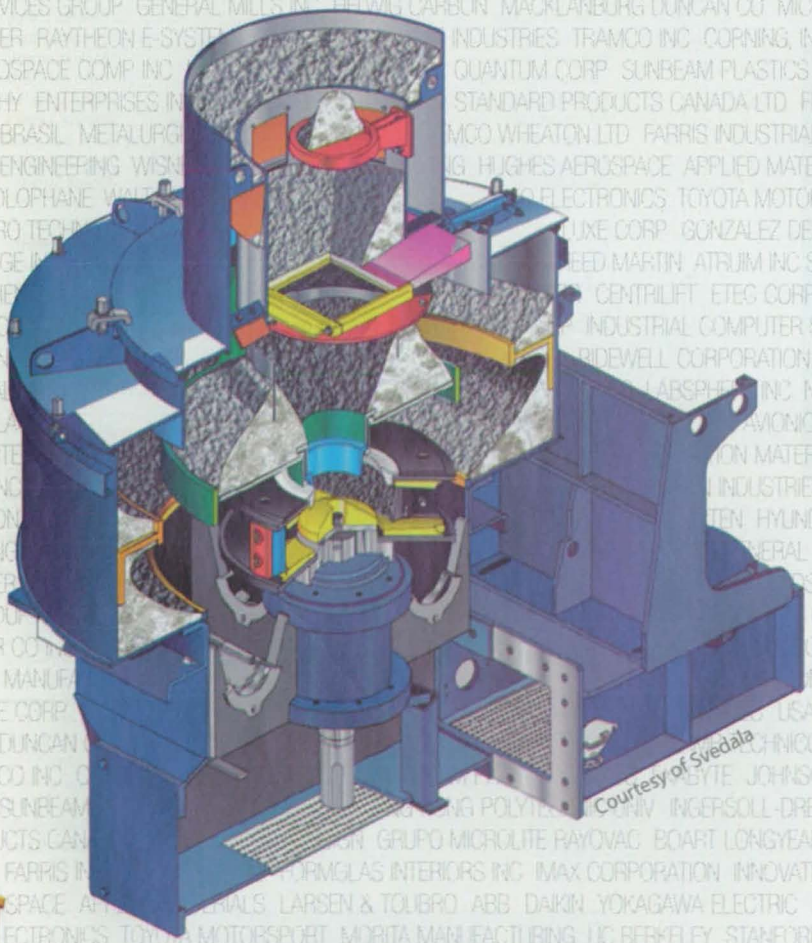

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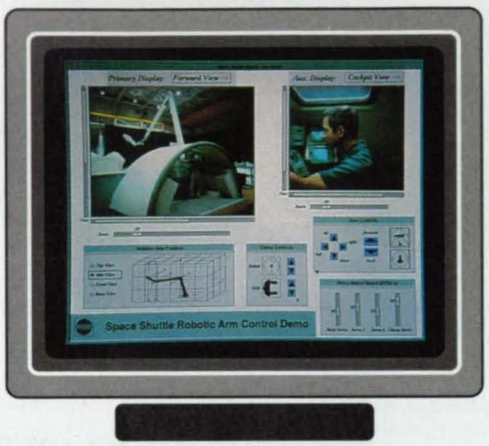

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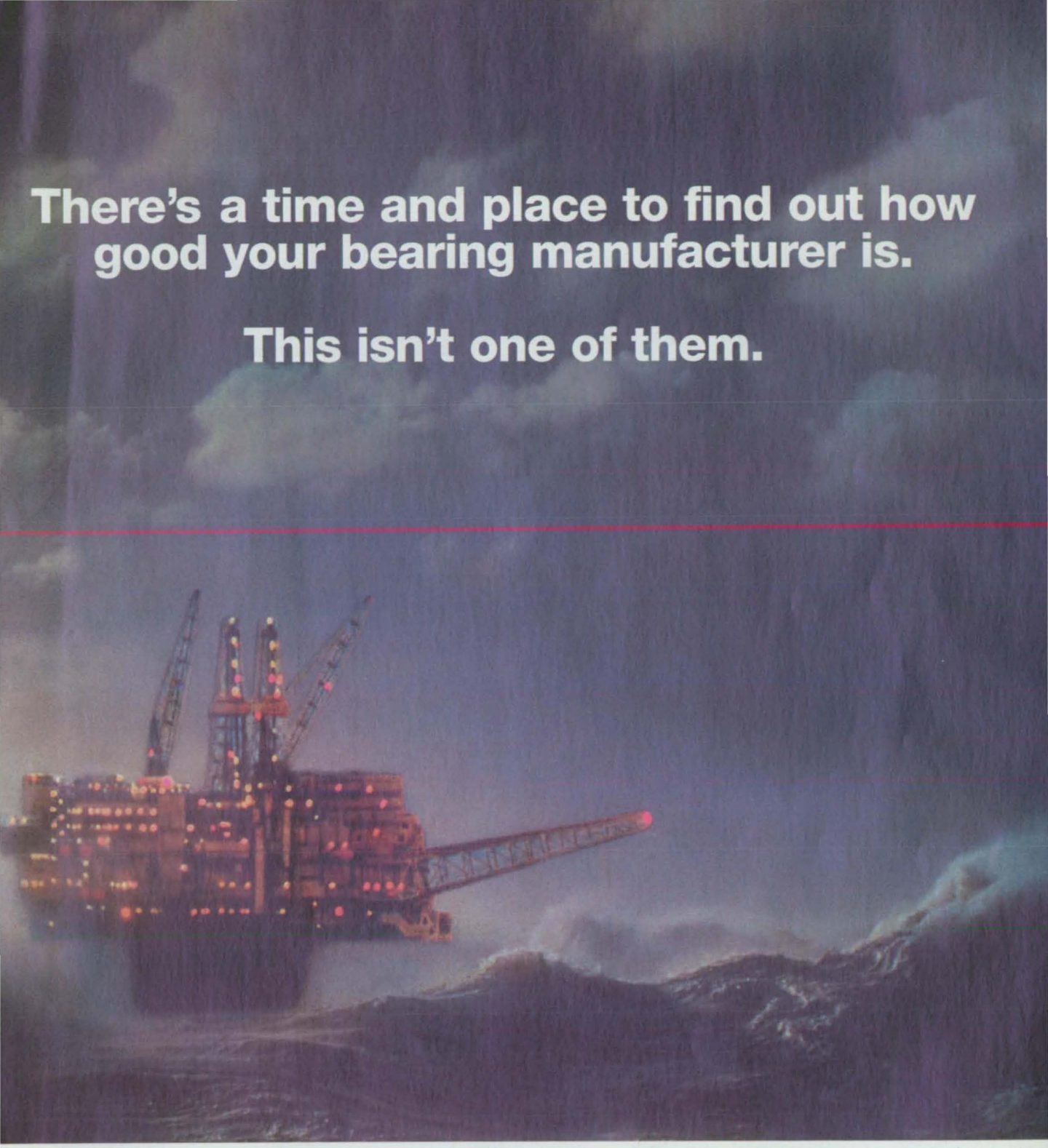

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NASA's Technology Sources

If you need further information about new technologies presented in *NASA Tech Briefs*, request the Technical Support Package (TSP) indicated at the end of the brief. If a TSP is not available, the Commercial Technology Office at the NASA field center that sponsored the research can provide you with additional information and, if applicable, refer you to the innovator(s). These centers are the source of all NASA-developed technology.

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Dryden Flight Research Center
Selected technological strengths: Aerodynamics; Aeronautics Flight Testing; Aeropropulsion; Flight Systems; Thermal Testing; Integrated Systems Test and Validation.
Lee Duke
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Goddard Space Flight Center
Selected technological strengths: Earth and Planetary Science Missions; LIDAR; Cryogenic Systems; Tracking; Telemetry; Command.
George Alcorn
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galcorn@gsfc.nasa.gov

Jet Propulsion Laboratory
Selected technological strengths: Near/Deep-Space Mission Engineering; Microspacecraft; Space Communications; Information Systems; Remote Sensing; Robotics.
Merle McKenzie
(818) 354-2577
merle.mckenzie@ccmail.jpl.nasa.gov

Johnson Space Center
Selected technological strengths: Artificial Intelligence and Human Computer Interface; Life Sciences; Human Space Flight Operations; Avionics; Sensors; Communications.
Hank Davis
(713) 483-0474
hdavis@gp101.jsc.nasa.gov

Kennedy Space Center
Selected technological strengths: Environmental Monitoring; Sensors; Corrosion Protection; Bio-Sciences; Process Modeling; Work Planning/Control; Meteorology.
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Langley Research Center
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Lewis Research Center
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Ann Heyward
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Marshall Space Flight Center
Selected technological strengths: Materials; Manufacturing; Nondestructive Evaluation; Biotechnology; Space Propulsion; Controls and Dynamics; Structures; Microgravity Processing.
Harry Craft
(205) 544-5419
harry.craft@msfc.nasa.gov

Stennis Space Center
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NASA Program Offices

At NASA Headquarters there are seven major program offices that develop and oversee technology projects of potential interest to industry. The street address for these strategic business units is: NASA Headquarters, 300 E St. SW, Washington, DC 20546.

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If you are interested in information, applications, and services relating to satellite and aerial data for Earth resources, contact: Dr. Stan Morain, **Earth Analysis Center,** (505) 277-3622. For software developed with NASA funding, contact the **Computer Software Management and Information Center (COSMIC)** at phone: (706) 542-3265; Fax: (706) 542-4807; E-mail: http://www.cosmic.uga.edu or service@cosmic.uga.edu.

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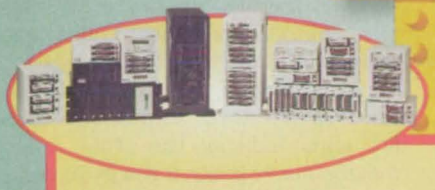

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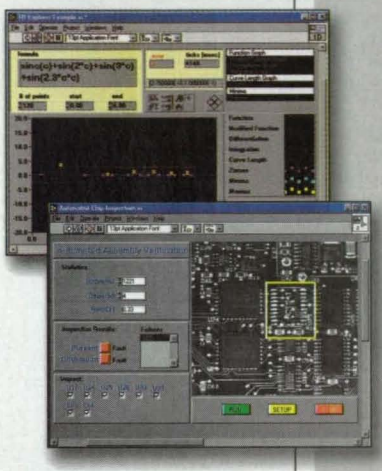

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NASA PATENTS

Over the past three decades, NASA has granted more than 1000 patent licenses in virtually every area of technology. The agency has a portfolio of 3000 patents and pending applications available now for license by businesses and individuals, including these recently patented inventions:

Scalable Wrap-Around Shuffle Exchange Network with Deflection Routing

(U.S. Patent No. 5,617,413)

Inventor: Steve P. Monacos, Jet Propulsion Laboratory

Current optical communications networks typically operate at a single frequency in a ring or bus topology. As computational and communications demands increase, such networks are inadequate to handle future requirements. This invention is a communication network including plural crossbar nodes, first apparatus for connecting the nodes in a first layer of links, and second apparatus for connecting the nodes in a second layer of links independent of the first layer. The network may further include third and fourth apparatuses connected similarly. Each layer is connected to the other at each one of the nodes. Preferably each layer corresponds to one recirculating network topology that closes in on itself. In the preferred embodiment, the network topology of each of the layers is that of a cyclic shuffle exchange network wherein the first and second layers include first and second rings of the connecting links.

For More Information Circle No. 765

Lightweight Ceramic Compositions of Carbon, Silicon, Oxygen, and Boron

(U.S. Patent No. 5,618,766)

Inventors: Daniel B. Leiser, Ming-Ta Hsu, and Timothy S. Chen, Ames Research Center

The researchers have produced a lightweight monolithic ceramic composition of carbon, silicon, oxygen, and boron that is able to retain its shape and strength when exposed to an oxidizing environment at 1200 °C, using a sol-gel method. The method comprises coating a carbon substrate with a sol that mixes silicon alkoxides and a borate ester, such as di- and tetrafunctional siloxanes and boron alkoxide, gelling the sol and heating the coated carbon substrate in an inert atmosphere to form the ceramic. Lightweight, highly oxidation-resistant ceramic tiles suitable for use in advanced space vehicle applications have been made by impregnating a porous carbon preform with the sol, followed by gelation, drying, and pyrolysis.

For More Information Circle No. 766

Series Connected Converter for Control of Multi-Bus Spacecraft Power Utility

(U.S. Patent No. 5,623,398)

Inventors: Raymond F. Beach and Andy Brush, Lewis Research Center

Spacecraft often use power from a solar array to charge a battery and supply loads through a regulating converter. Power from the battery is supplied to high- and low-voltage buses through separate converters processing all of the power to the buses. But processing full power generates substantial losses, taxing cooling systems and requiring cooling to be sized for relatively high peak loads. The present invention provides a power system using series-connected regulators employing a bypass loop around a DC-DC converter. The loop connects a hot input of the converter to a return output, preferably through an inductor. Part of the current from the source passes through the bypass loop to the power bus. The converter bucks or boosts the voltage from the source to maintain the desired voltage at the bus. Thus only part of the power is processed through the converter.

For More Information Circle No. 767

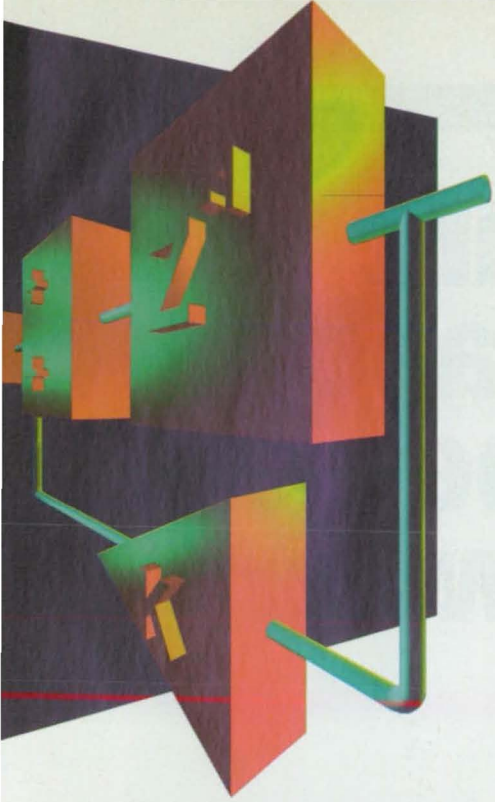
Three-Dimensional Co-Culture Process

(U.S. Patent No. 5,627,021)

Inventors: Thomas J. Goodwin and David A. Wolf, Johnson Space Center

The process of the present invention co-cultures a variety of cells to produce tissue that has three-dimensionality and some of the characteristics of *in vivo* tissue. It forms and maintains three-dimensional tissue of such a size as to create a multicellular organoid differentiation model. The co-culturing process optimizes a group of culture environmental conditions, even as the culturing progresses, in a manner that greatly enhances the capability to form and maintain three-dimensional living tissue from either dissociated source cells or intact tissue resections.

For More Information Circle No. 769



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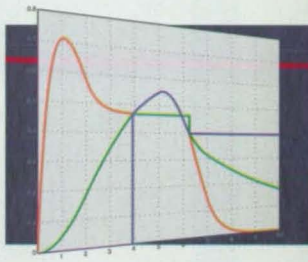

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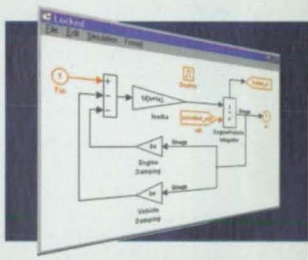

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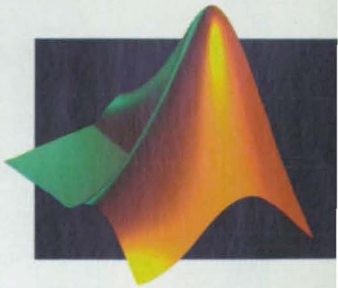

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For More Information Circle No. 529

Guest Editorial

by Carl Ray,
Small Business
Innovation Research/
Small Business Technology
Transfer (SBIR/STTR)
Executive

Small Business: Vital Link to NASA's Future

As the new millennium dawns, NASA faces challenges as well as opportunities that our parents and grandparents only dreamed about. Across the nation, NASA scientists and engineers are performing the research and development required to maintain United States leadership in civil aeronautics, aviation, and space exploration, and, at the same time, continuing our strong customer focus particularly with regard to developing and maintaining NASA-industry partnerships.

NASA achievements continue to inspire and encourage a new generation of innovators who will lead our nation through the next century. To accomplish our goals, NASA must generate greater yields on the investments made by the citizens of this nation; this requires continuous changes in the way NASA and its family of contractors do business. Many of these changes are underway. The primary objective of these changes has been to reduce the taxpayer dollars required to carry out NASA programs, but a secondary goal is to increase the opportunities for the small-business community to be part of the NASA effort by providing it with greater flexibility and facility in its innovation efforts, with less bureaucratic burden. The SBIR/STTR programs are one of NASA's vehicles to accomplish this objective.

Small businesses are on the cutting edge of technology, and their bold and aggressive approaches to innovation clearly mirror NASA's spirit.

NASA views the cadre of small businesses, including women- and minority-owned businesses, as a vital link to the agency's future. They are on the cutting edge of technology, and their bold and aggressive approaches to innovation clearly mirror NASA's spirit of doing business better, cheaper, and faster. We are very excited about the possibilities that these companies bring to the agency. The SBIR/STTR programs provide an avenue for small businesses to meet many of NASA's research and development needs.

The SBIR program was established by Congress in 1982 to provide small businesses with increased federal R&D opportunities. The STTR program, established within the SBIR legislation in 1994, is modeled after its parent program but focuses on translating U.S. leadership in basic research and many areas of applied science into an economic advantage.

The SBIR/STTR programs are both designed to allow small businesses and research institutions to participate in the nation's annual multi-billion-dollar investment in R&D. The aim of an SBIR/STTR-funded project is to produce new technologies that have high commercial potential and will advance U.S. growth in productivity and international market competitiveness.

Starting with this issue of *NASA Tech Briefs* magazine, the NASA SBIR/STTR management embarks on an innovation of their own to share the excitement and opportunities of these two programs with the broader technical community.

In this and periodically in following issues, you will learn more about NASA's SBIR/STTR programs. There will be articles on program participation and events, but most importantly, briefs from successful small businesses describing aspects of their technical and commercial accomplishments resulting from their participation in these programs. Two such briefs appear in this issue: "Electronically Switchable Bragg Gratings (ESBGs)" (page 42), reporting on work done by Foster-Miller Inc. and monitored for NASA's SBIR program by Marshall Space Flight Center, and "Optical Air Mass Flux Sensor for Aeroengine Monitoring and Control" (page 56), reporting on work done by Physical Sciences Inc. and monitored by Dryden Flight Research Center.

We are very excited about the NASA SBIR/STTR "success briefs" as an addition to this renowned technology digest and hope that you will share the excitement in reading them.

To learn how to apply for and win SBIR grants and contracts, attend the 1997 National Small Business Innovation Research Conferences, to be held in Washington, DC's Renaissance Hotel October 14-16 and Phoenix, AZ's Hyatt Regency October 27-29. For more information, call the SBIR Conference Center at (360) 683-5742; fax (360) 683-5391; on-line: www.zyn.com/sbir.

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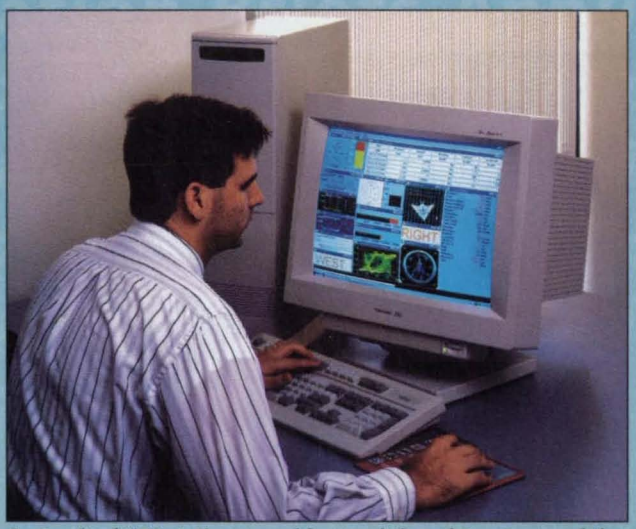

Customized VTS stations provide a real-time data stream of the space shuttle's flight performance.

AlliedSignal Technical Services Corp. has re-engineered NASA's ground network stations to reduce life cycle costs for the space shuttle. The upgrade includes five Windows NT-based Visual Test Systems (VTS), which will be used to develop real-time range safety data in the laboratory and at the launch site. Three systems will be installed at the Merritt Island Launch Annex in Florida; another will be installed at the Electronic Systems Test Laboratory at NASA's Johnson Space Center in Houston; and the fifth system will go to the Network Engineering Development Laboratory at NASA's Goddard Space Flight Center in Greenbelt, MD.

"The VTS met our hard requirements for a commercial off-the-shelf PC solution that made use of a database for parameter extraction," said Ed Richards, implementation group leader at AlliedSignal. The systems come with a Software Development Kit that lets NASA customize the system to its requirements. "We needed flexible and reliable telemetry processing capabilities to meet range safety requirements for the shuttle," Richards explained.

The VTS is a Windows-based real-time data acquisition system with an intuitive interface for configuring hardware boards, including decommutators, bit synchronizers, MIL-STD-1553 modules, analog input modules, and digital/analog output modules. Data is distributed from a server to multiple clients via a network-based environment. The VTS stations will acquire shuttle data, strip parameters, and reassemble them as a serial output range safety data stream. The real-time data stream will be delivered to NASA's Range Safety Officers to verify that the vehicle flight performance remains within the safety environment. Generally, the data will come from the shuttle's flight systems and computers, which gather data from the external fuel tank, solid rocket boosters, and main engines. "The whole idea is to maintain a clear picture of the shuttle's flight performance, starting with the ignition sequence, through powered flight," said Richards.

For More Information Circle No. 756

Software Helps Grab Comet by the Tail

MuSE (Multidimensional, User-oriented Synthetic Environment) software
MuSE Technologies
Albuquerque, NM
505-843-6873
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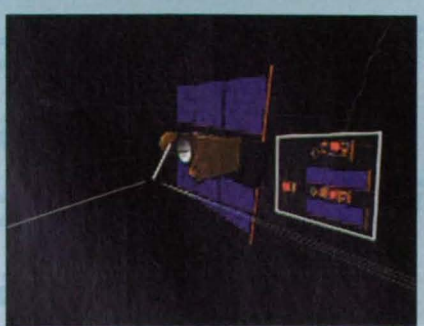
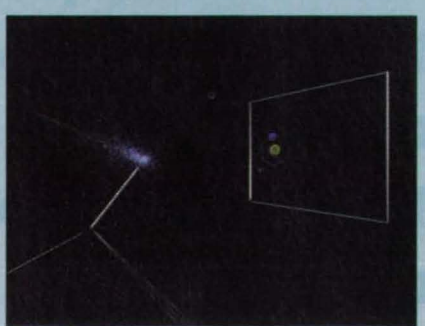
NASA's Stardust mission involves sending a spacecraft the size of an office desk to loop around the sun twice, collecting interstellar dust before a rendezvous with the Wild-2 comet in 2004. The spacecraft will pass the comet at 35,000 miles per hour while it collects comet dust and other debris. The craft will return to Earth with photos and samples in 2006, arriving home as the first U.S. mission to robotically obtain samples in deep space for analysis on Earth.

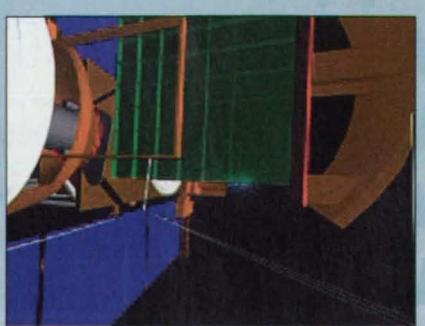
Last year, NASA conducted a rehearsal — in a virtual environment — of the encounter of the Stardust spacecraft with the comet. During the mission simulation, MuSE integrated actual data from previous space probes and technical drawings of the proposed craft, allowing NASA engineers to "fly" as close as possible to the comet without leaving the ground. Precision is crucial since the spacecraft and the comet will pass at right angles, the craft moving at nine times the speed of a rifle bullet. Critical to the mission is getting close enough to collect significant material, while not being endangered by the comet's debris.

With the MuSE software, NASA scientists were able to simulate approaching the comet from different trajectories and attempt to get as close as possible. During the simulation, when the virtual spacecraft flew too close to the comet, mission planners could hear the sound of objects striking the craft and see the impact of each "fly by" from different vantage points. MuSE-developed instruments measured changes in particle density and simulated potential destabilization of the craft.

For More Information Circle No. 757







(Left to right) 1) The Stardust spacecraft is shown in initial orbit around Earth, with cross-sections displayed on the craft wall; 2) the craft has approached the comet as it moves away from the Sun, with the full encounter running on the side wall; 3) the spacecraft approaches the comet with its collector extended.

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BENTLEY

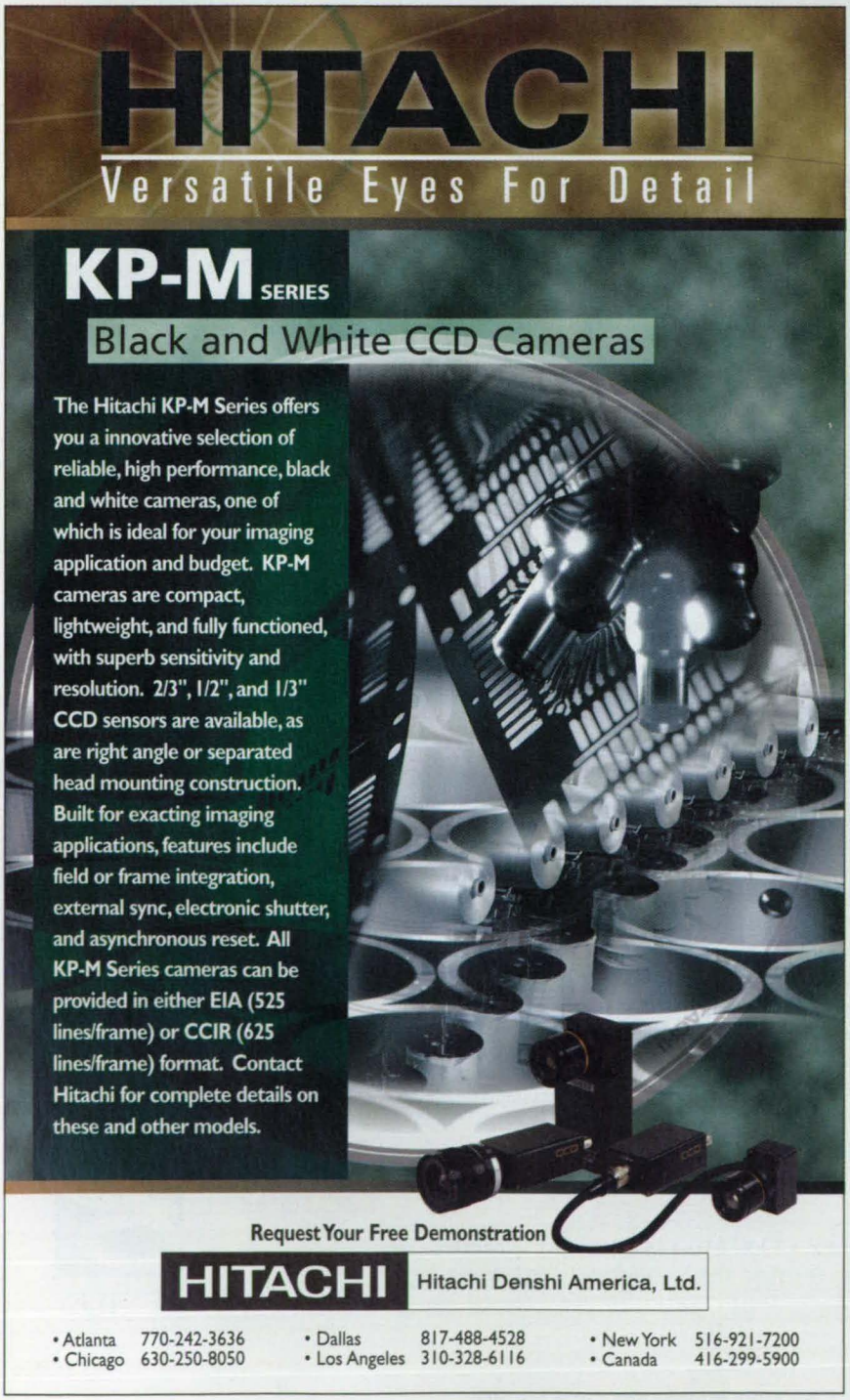
Commercialization Opportunities

Telerobot Control for Microsurgery

This system scales down the motion of a surgeon's hand to a very precise, smooth movement, which is critical in operations of the eye, brain, ear, and face and in the repair of fine blood vessels and nerves.
(See page 46.)

Hydrogen-Fire-Detector Calibration Unit

A microprocessor-controlled tabletop unit uses a krypton lamp for testing hydrogen-fire detectors. It eliminates the need to ignite hydrogen to run such tests and is therefore safer.
(See page 46.)



Better Cells for Multiple-Pass Absorption of Light in Gases

Improved cells offer better accuracy, are smaller, and cost less than earlier models. These cells are used to analyze gases via light absorption.
(See page 52.)

Electrochemical Process for Treatment of Wastewater

Three sequential subprocesses treat wastewater that contains various proportions of urine, laundry water, and bath water. Contaminants are reduced to 500 micrograms per liter, a level considered potable.
(See page 58.)

Modified CVI Process for Making SiC/SiC Composites

This process utilizes a sacrificial layer of SiC fiber preform that can be removed easily by scraping or tapping. The process eliminates a time-consuming, costlier grinding step.
(See page 64.)

Unsymmetrical Squaraine Dyes for Nonlinear Optics

Dyes have been invented that can be used in a variety of optical devices that exploit nonlinear optical properties to change frequency and/or polarization of light in useful ways. Second-harmonic generators, spatial light modulators, parametric oscillators, and some interferometers can benefit from this development.
(See page 65.)

Portable Computer Workstations for Engineering Teams

Ergonomic computer workstations have been designed to allow flexible office-seating arrangements among engineers or other workers in ways that promote the best levels of communication and collaboration.
(See page 74.)

Rolled-Up Ramp Deploys Itself on Command

A ramp originally designed for the Mars Pathfinder can be stowed as a compact cylinder and can be readily unfurled by its own spring force. The design can be adapted to serve as an emergency-exit ramp for buildings, land vehicles, and aircraft.
(See page 80.)

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Neural-Network Modules for High-Speed Image Processing

These modules would offer unprecedented computational power in small, low-power packages.

NASA's Jet Propulsion Laboratory, Pasadena, California

JPL has recently designed, fabricated, and demonstrated custom ICs for high-speed image processing. Derived from highly parallel computing architectures based on neural network models, these circuits are implemented with JPL-pioneered extremely low-power neuron and synapse circuit elements. Furthermore, their ultra-low power and high-speed characteristics are making it possible for the first time to integrate multiple chips in 3-dimensional (3-D) modules (sugarcube-sized chipstacks).

Denoted "neuroprocessing modules" (NPMs), these 3-D packaged devices would be capable of processing images at rates of the order of 10^{12} operations per second. The original NPMs are intended for military use for recognition of targets by comparison of features in infrared images with previously recorded images of known targets. Potential civilian applications for NPMs include artificial vision, speech recognition, and autonomous control for robots.

The NPMs offer unprecedented computing ability in small packages. They include novel high-speed analog circuits that can operate at temperatures from 77 to 350 K and consume little power. This combination of high computing speed, low power, and small size facilitates integration with other compact, low-power, high-speed circuitry with which NPMs would be required to interact.

A typical NPM would consist of 64 identical neuroprocessing chips and would process the analog outputs (each containing 8 to 12 bits of information) from a 64 × 64 array of infrared photodetectors. Thus, for example, an NPM chip would include a 64 × 64 synaptic array plus a multistage crossbar switch, digital logic circuits, and input/output (I/O) pads (see figure). During each frame cycle, the image information embodied in the photodetector outputs would be compared with stored information on at least 64 known targets. The time needed for signals from the photodetectors to be processed by a 3-D neural network in an NPM would be about 200 ns: this would be short enough to enable processing of 1,000 image frames per second.

This work was done by Tuan Duong, Taher Daud, and Anilkumar Thakoor of Caltech, and Chris Sauders of Irvine Sensors Corp. for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Systems category,* ***or circle no. 124*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

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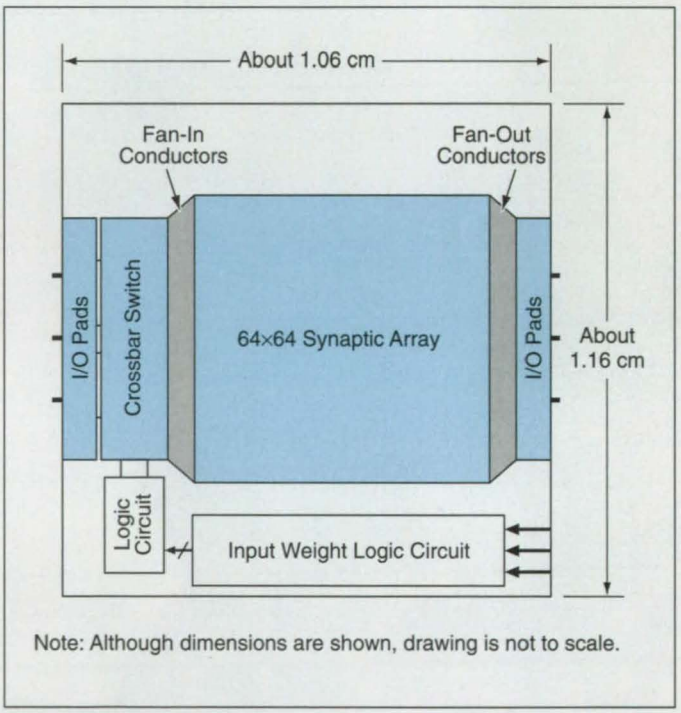

A **Typical NPM** would be no larger than a sugar cube, yet it would contain integrated circuitry capable of processing the output of a 64 × 64 array of infrared photodetectors at a rate of 1,000 frames per second.

Reconstruction of Images From Circular-Scan Sensors

Images can be reconstructed faster than before.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improved algorithm for reconstructing images from the outputs of circular-scan sensors has been devised. With relatively minor variations, the algorithm is applicable to data acquired by diverse circular-scan sensors (see Figure 1), including those of holographic synthetic-aperture radar (HSAR), x-ray computer-aided tomography (CAT), magnetic-resonance imaging (MRI), positron-emission tomography (PET), and ultrasonic-reflectivity tomography (URT). It can even be applied to data acquired by sonar and seismic sensors.

One older algorithm of this type, known as the convolution back-projection algorithm, has been popular in computer-aided tomography because it offers superior image quality and ease of adaptation to fan-beam geometry. Another one, known as the direct Fourier algorithm, is highly efficient in computation, but it depends on the use of a Cartesian coordinate grid and,

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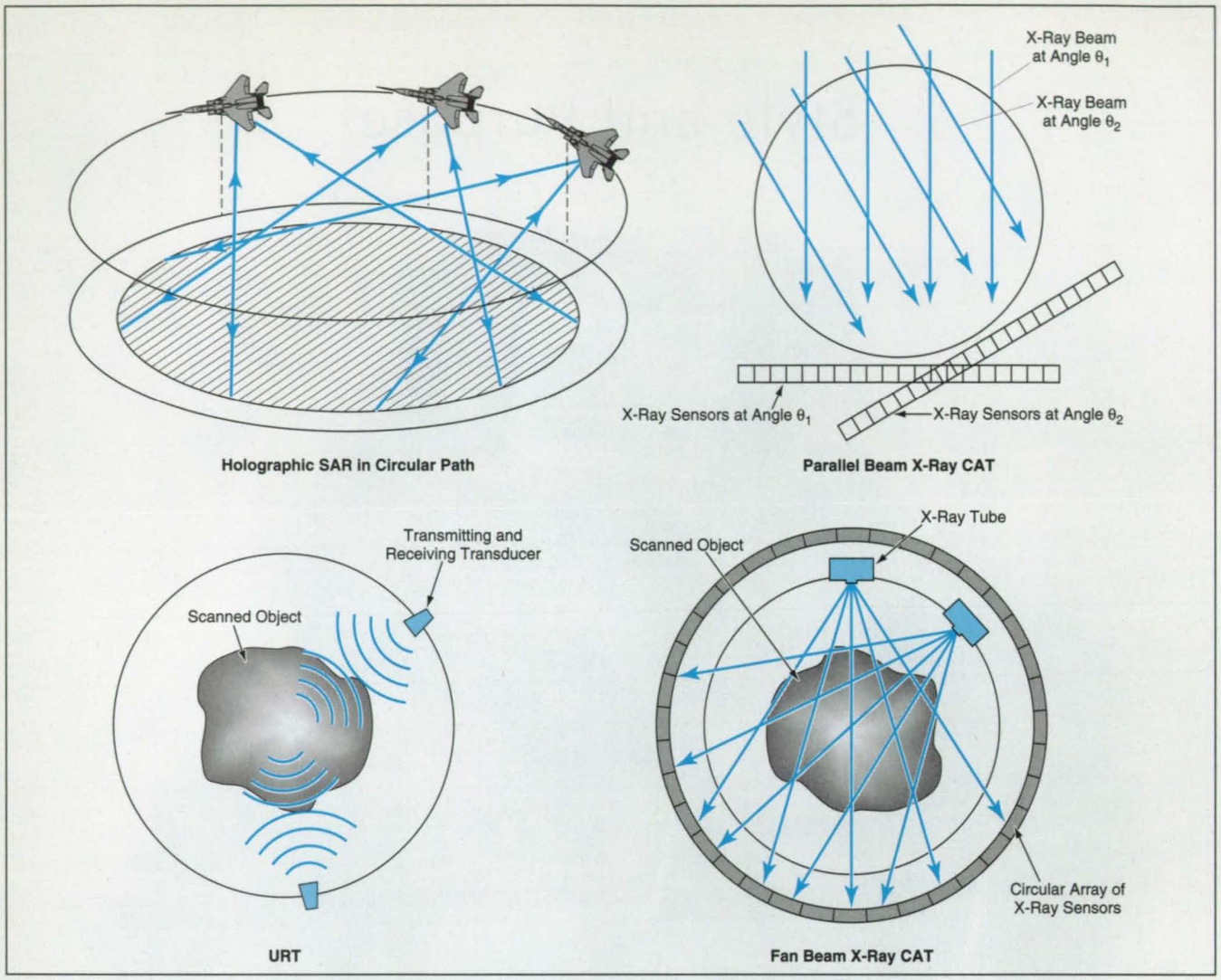

Figure 1. **Circular Scans** with various sensors generate data that can be processed to reconstruct images of the scanned scenes. The algorithm described in the text can accommodate these and other sensors and variations of the basic circular scanning geometry.

therefore, its image quality depends on the interpolation subalgorithm used to transform the signal spectrum into the Cartesian coordinates. Moreover, the direct Fourier algorithm applies to parallel-beam CAT only.

The improved algorithm overcomes the limitations of the direct Fourier algorithm and offers a computational efficiency between two and six times that of the convolution back-projection algorithm. Before images are formed, all computations are performed in polar coordinates. Polar-to-Cartesian transformation is finally applied to the reconstructed image for image display purpose. Based on the circular symmetry, this algorithm performs fast Fourier correlation in the azimuth dimension.

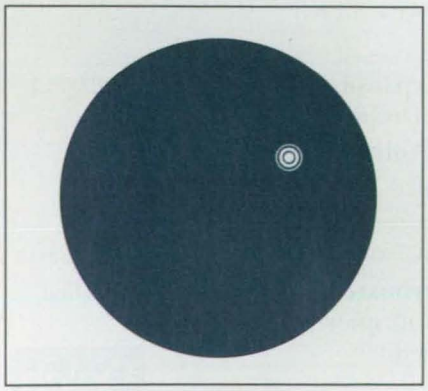

Figure 2. This **Image of a Point Target** was generated by applying the improved algorithm in a computer simulation of HSAR or URT, using a pulse with a bandwidth of 0.133 × its carrier frequency. The PSF in this image exactly follows that of Fraunhofer diffraction by a ring aperture.

The reference functions used in the improved algorithm are the amplitude-weighted two-dimensional spectra of the point-target responses (PTRs). [A PTR can be regarded as an extended or "blurred" version of a conventional point-spread function (PSF). The PTR is the PSF-blurred-curved-line response obtained from a point target imaged by a wide-beam circular-scan system like HSAR.] A reference function is updated for each range bin to achieve exact focusing. By choosing proper weighting functions, this algorithm is capable of generating an ideal PSF like that predicted for Fraunhofer diffraction by a circular aperture (see Figure 2). Further shaping of the PSF can be achieved by use of extra weighting. The high computational efficiency of this algorithm is attributable to the characteristics of the two-dimensional spectrum of the PTR.

This work was done by Michael Y. Jin of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mathematics and Information Sciences category,* ***or circle no. 158*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

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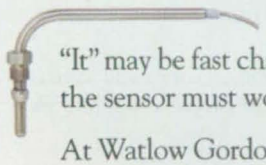

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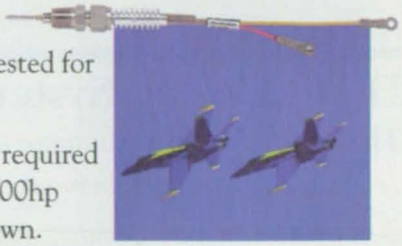

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For More Information Circle No. 545

Advanced X-Ray Imaging Spectrometer

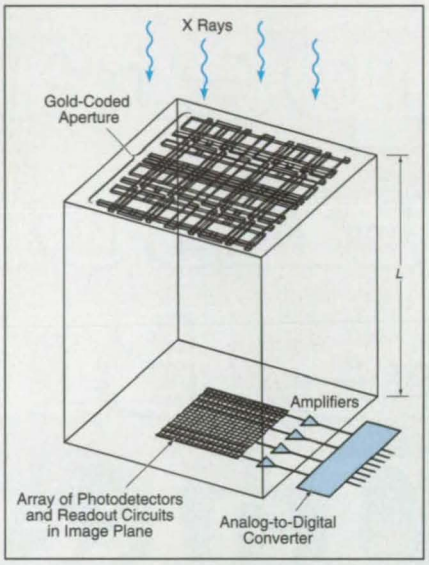
Increases in sensitivity and resolution are made possible by development of improved detectors used in conjunction with a coded aperture.

NASA's Jet Propulsion Laboratory, Pasadena, California

An advanced x-ray imaging spectrometer (AXIS) with electronic readout features high sensitivity with high spatial and spectral resolution. Prior to this innovation, to perform x-ray imaging and x-ray spectroscopy, it has been necessary to use separate instruments, so that it has been difficult or impossible to associate x-ray spectra with x-ray image features. Furthermore, prior photographic-film and electronic x-ray-imaging instruments have yielded poor spatial resolution and required long exposure times (because of low sensitivity). Offering a capability for sensitive, high-resolution imaging with fine spectroscopy within each pixel, the AXIS opens new possibilities for x-ray observations in astrophysics, laboratory microscopy, industrial inspection, and medicine.

The image plane in the AXIS consists of electronic circuitry in a 1,024-by-1,024 array of pixels containing x-ray photodetectors and on-pixel readout circuits. The detector array is made from high-purity, deeply depleted silicon. The deeply-depleted characteristic results in high sensitivity to x rays at photon energies up through 40 keV. The use of high-purity silicon with on-pixel circuitry results in low leakage current and low noise, enabling fine spectroscopy at or near room temperature. In circuitry outside the image plane, the outputs of the on-pixel preamplifiers are further amplified, then digitized.

To achieve high spatial resolution for imaging, it is necessary to modulate the incoming x rays. For this purpose, the x rays pass through coded aperture (see figure). The coded aperture is fabricated from gold using semiconductor-processing techniques. [Such use of coded apertures to produce spatial modulation for imaging was described previously in "Gamma-Ray Imager With High Spatial and Spectral Resolution" (NPO-19140), *NASA Tech Briefs*, Vol. 20, No. 2 (February 1996), page 49 and "Gamma-Ray Imaging With Two-Dimensionally-Coded Apertures" (NPO-19331), *NASA Tech Briefs*, Vol. 20, No. 11 (November 1996), page 4a.] The digitized pixel outputs are sent to a computer. Using a deconvolution algorithm based on the known geometric relationships among the x-ray source, the coded aperture, and pixels, the computer reconstructs an image of the x-ray source from the digitized detector pixel outputs with a spectrum associated with each image pixel. The spatial resolution of the image can be increased (trading field of view) by increasing the distance, *L*, between the aperture plate and the image plane.



Coded Aperture spatially modulates the incident x rays. The aperture pattern is designed so that the resulting pattern of x-ray intensity on the image plane can be deconvolved to extract an image of the x-ray source.

This work was done by John L. Callas and George A. Soli of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category,* ***or circle no. 188*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

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Digital Video System Images Damaged Gears During Operation

The progression of damage can be documented more quickly, thoroughly, and easily.

Lewis Research Center, Cleveland, Ohio

A high-speed digital video imaging system captures still images of individual teeth on gears meshing at high speed on a gear-test rig. Each gear-tooth image documents the progression of the wear, pitting, spalling, and fractures that lead to overall gear failure. Heretofore, images documenting gear failure were acquired only during post-test analysis and thus did not provide real-time study of the degradation that leads to failure. The high-speed digital imaging system is integrated with another system that measures vibrations and processes the measurements to detect indications of damage. Analysis of the gear-tooth images coupled with vibrational data acquired at the same time should make it possible to better classify vibrational signatures according types and degrees of damage and to improve understanding of the events that lead to failure.

The imaging system (see figure) includes a digital video camera aimed at passing gear teeth. The system is located in a darkened room. Illumination is provided by a fiber-optic-coupled stroboscope with a 5-μs pulse duration, which is brief enough to capture images without noticeable blur at typical gear speeds. A magnetic probe senses the rotation of the gear and generates a once-per-revolution pulse. A shaft-angle-encoder circuit divides the once-per-revolution pulses into pulses at smaller intervals corresponding to the passage of individual gear teeth in front of the camera. A frequency divider processes the gear-tooth-passage pulses into stroboscope-trigger pulses at intervals long enough to ensure that only one flash occurs during the camera

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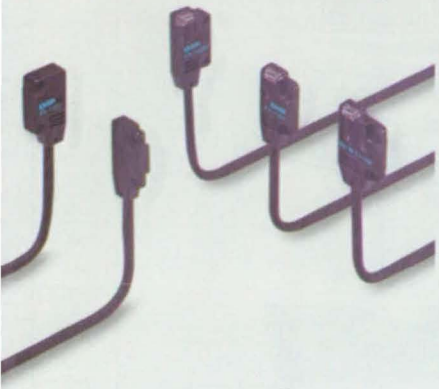

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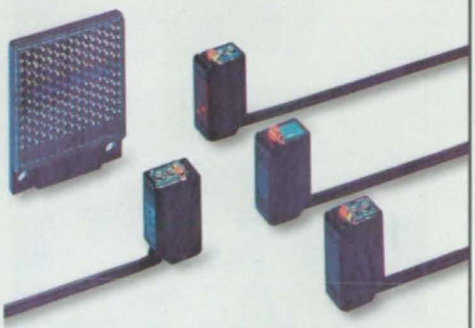

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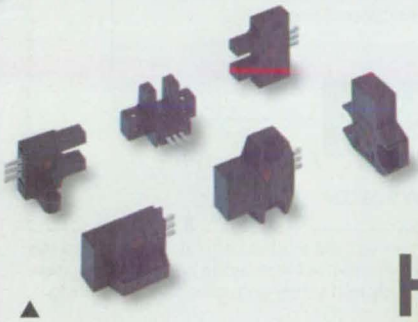

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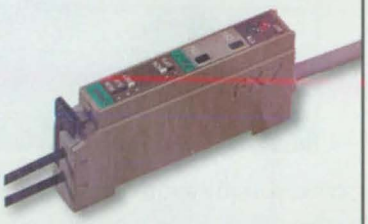

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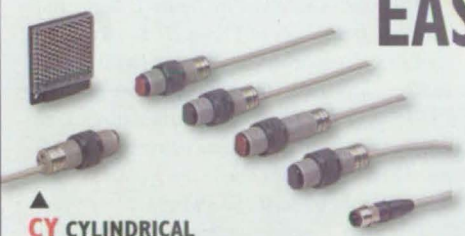

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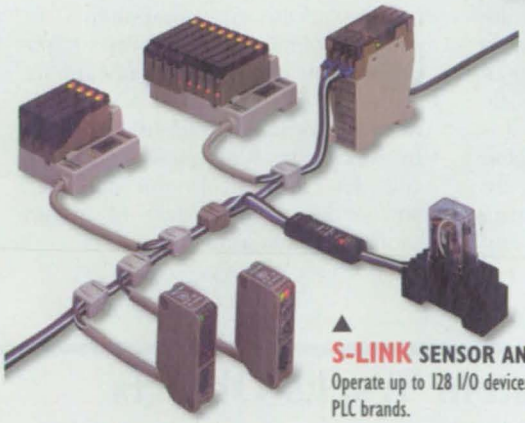

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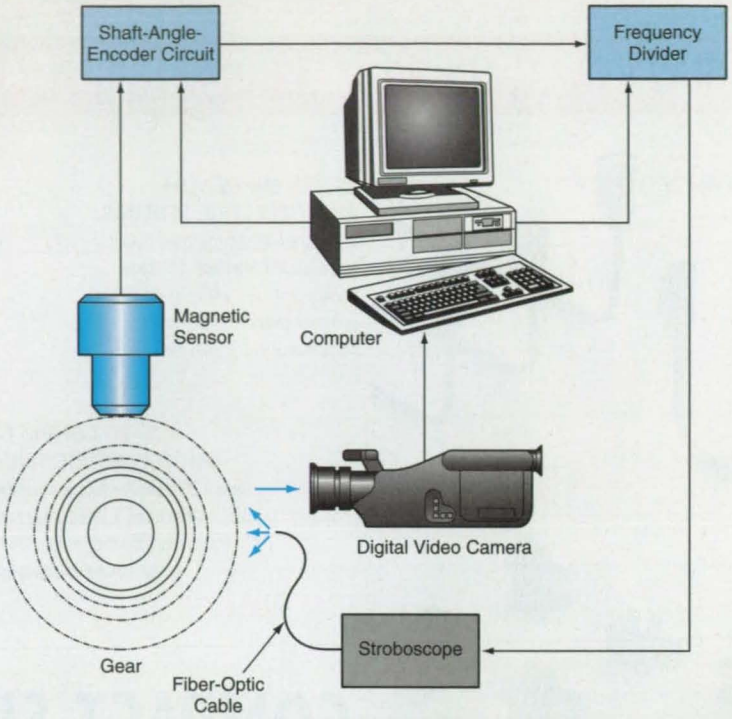
For More Information Circle No. 570

TYPICAL IMAGE SHOWING DAMAGED GEAR TEETH



IMAGING SYSTEM

The High-Speed Digital Video Imaging System captures still images of gears meshing at high speed. The system will aid studies of gear damage and the development of techniques for vibration monitoring to detect incipient damage. In comparison with film-based photographic imaging systems, this system provides for easier viewing and storage of data; it gives immediate visual feedback and there is no need for costly and time-consuming film processing.

integration time of 1/30 second.

The imaging system operates automatically, under control by a computer that runs special-purpose software. Each time the computer in the vibration-measuring system determines that vibrations have exceeded a threshold level, it signals the computer in the imaging system to begin a sequence of operations to acquire images of gear teeth. For each tooth, the camera is turned on for its integration time; during that time, at the instant when the designated tooth passes in front of the camera, the stroboscope is flashed to produce a single-exposure still image of the tooth. The images are stored in the frame-grabber memory. This process is repeated until images for all the gear teeth have been acquired, then they are transferred to a hard disk in the computer. The computer then resets, and the system awaits the next signal from the vibration-measuring system.

This imaging system is potentially adaptable to numerous other applications in which there are requirements for automatic acquisition of images of moving objects or of events that manifest themselves only during rapid motion. Examples of potential uses include the following:

- Inspection during bottling processes to verify fill levels and capping;
- Detection of improperly mounted or missing electronic components or detection of missing automotive components during manufacturing operations;
- Detection of stamps and preliminary sorting in postal operations;
- In banking, tracking bundles of checks and detecting checks out of order, and/or identifying stacks of money short in their amounts;
- In printing, imaging the product to detect defects without shutting down for false alarms; and
- Inspecting power-generation and manufacturing machinery during operation to identify troubles that cannot be seen when the equipment is shut down.

This work was done by James J. Sims and Howard Broughton of Cortez III Service Corp. for **Lewis Research Center.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Systems category,* ***or circle no. 175*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

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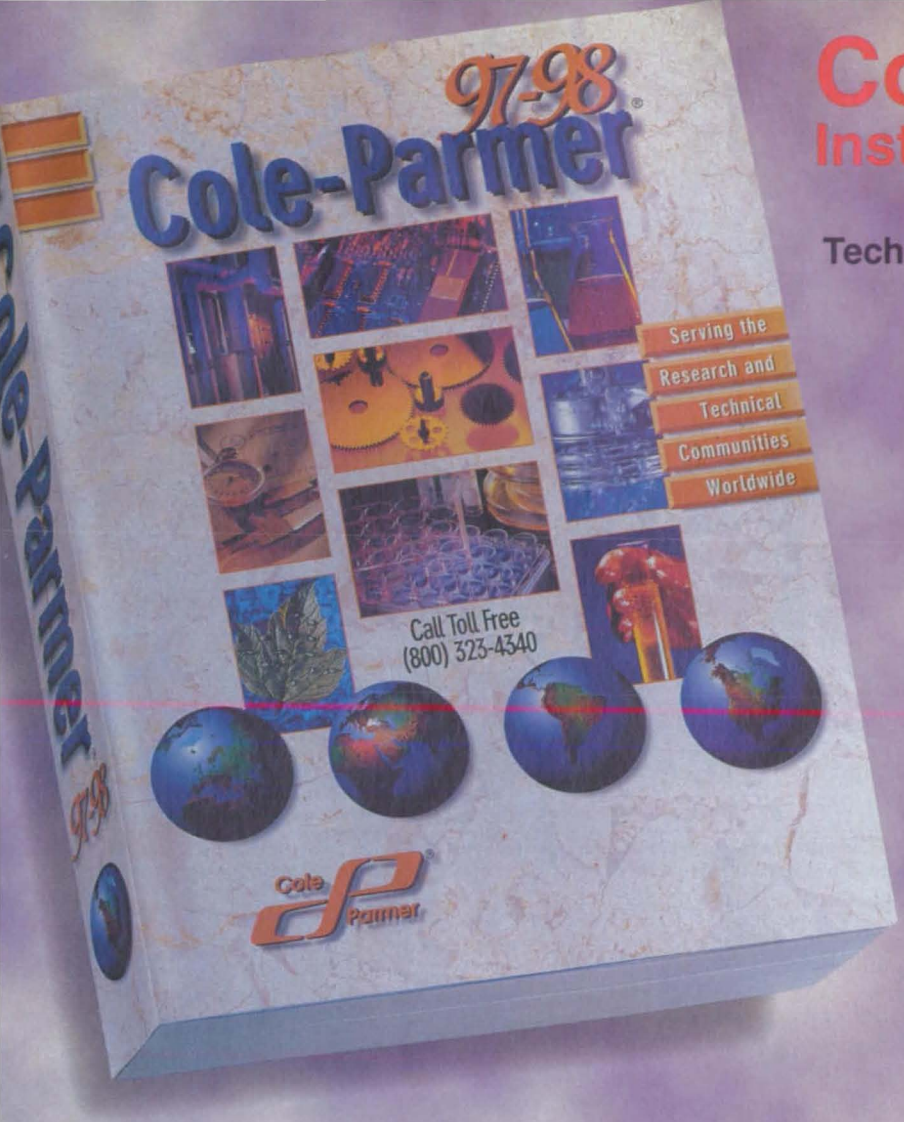
Image-Analysis System Tracks Objects

A tedious manual image-analysis process has been automated.

Lewis Research Center, Cleveland, Ohio

A personal-computer-based image-processing system digitizes video or film images and then performs various forms of motion analysis by tracking objects and/or features. The system was designed specifically for analysis of the types of images found in microgravity combustion and fluid experiments; the object and/or features to be tracked can include flame fronts, particles, droplets, and fluid interfaces. Since this is not a real-time tracking system but a post-analysis tracking system, the image sequences to be analyzed have been previously recorded on a



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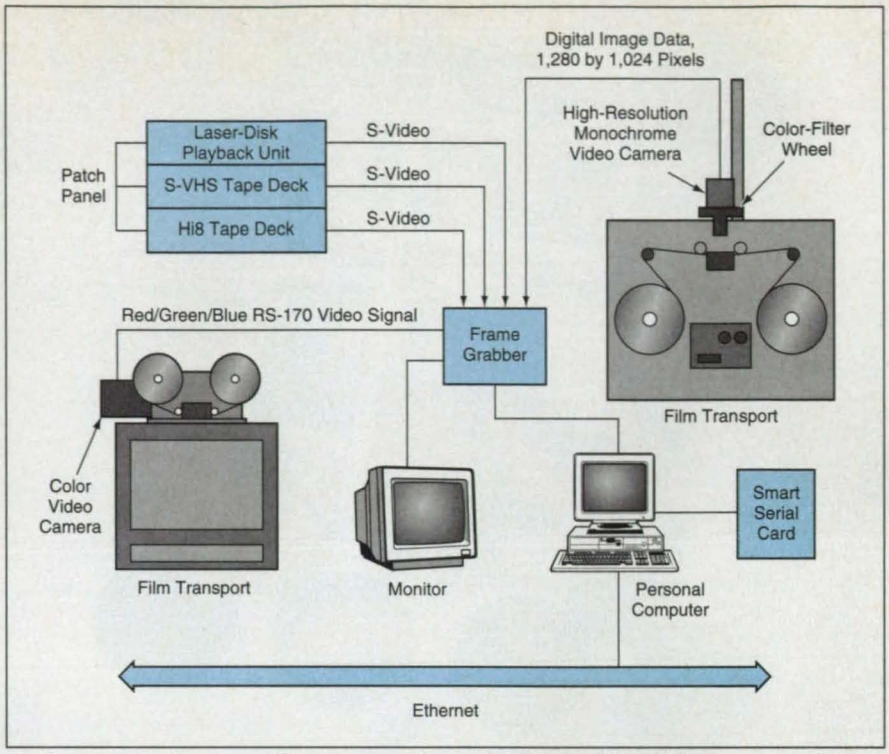

The **Computer Analyzes Image Data** from any of several playback units, which it controls. Special-purpose software tracks moving objects and/or features in video or photographic image frames.

standard photographic movie film or video tape. Digital image input in the form of image files can be also accepted. The system automates what has previously been a tedious, time-consuming image-analysis process in which a technician or a scientist visually examined and manually took measurements directly from a displayed image, repeating this process until all the image frames were analyzed.

The system (see figure) consists of individual hardware components working under computer control to achieve a high degree of automation. The most important hardware components include 16-mm and 35-mm film transports, a high-resolution digital camera mounted on a *x-y-z* micropositioning stage, an S-VHS tapedeck, a Hi8 tapedeck, a video laserdisk, and a framegrabber. All of the image-input devices are remotely controlled by a computer. Software, called Tracker was developed to integrate the overall operation of the system, including device frame incrementation, grabbing of image frames, image processing of the object's neighborhood, locating the position of the object being tracked, and storing the coordinates to a file. This process is performed repeatedly and automatically until the last frame is reached. Several different tracking methods are supported, including threshold reduction, template matching, and a spline-based active contour model method. The types of data obtained from Tracker are positions, velocities, area measurements, centroids, object outlines and shapes, time sequences of line profiles, 3-d areas, intensity and color characteristics, and size measurements, all as a function of time. The data are presented in a format ready for graphing or further analysis via other packages.

Optionally, the system can be operated in a semiautomatic mode, in which the user manually locates an object by using a mouse to move a crosshair on the display. All other steps are performed as in the automatic mode.

This work was done by Robert B. Klimek and Ted W. Wright of **Lewis Research Center** *and Robert S. Sielken of Trinity University. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Systems category,* ***or circle no. 167*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

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Swept-Frequency Fiber-Optic Readout From Multiple Sensors

Readouts from individual sensors are distinguished by frequency rather than by pulse-travel time.

NASA's Jet Propulsion Laboratory, Pasadena, California

A technique of frequency-domain reflectometry has been devised for obtaining readouts from multiple sensor transducers that (a) reflect light to degrees indicative of quantities that one seeks to measure and (b) are connected to, and located at various positions along, an optical fiber. In this technique, a beam of light that interrogates the sensors is amplitude-modulated at a radio frequency that is swept linearly. The beam is launched into the fiber from an input end, travels to the various transducers, and is reflected back to the input end (see figure). As explained in more detail below, the modulation in the light reflected back to the input end can be decomposed into frequency components — a separate frequency component associated with each transducer — and the amplitude of each component can be taken as an indication of the quantity sensed by the corresponding transducer.

This technique offers advantages over time-domain reflectometry as applied to such an array of sensors. In time-domain reflectometry, one would interrogate the transducers by use of a pulsed beam of light in order to distinguish the returns from the individual transducers in terms of their individual round-trip pulse-travel times. The pulses would have to be short enough and the sensors would have to be located far enough apart, consistent with the pulse duration, so that pulses returned from different sensors did not overlap. Thus, time-domain reflectometry would entail restrictions on both the placement of transducers and on pulse durations. Shorter pulses contain less energy than do longer pulses and thus necessitate longer signal-averaging times to obtain adequate measurement sensitivity at low signal levels. Long averaging times are not acceptable in many systems in which real-time or near-real-time responses are required; for example, in process-control applications. In the present swept-frequency technique, the minimum acceptable distance between sensors is much less than in time-domain reflectometry. Moreover, the averaging time needed to achieve a given level of sensitivity is less than in time-domain reflectometry.

Suppose that the interrogating beam of light is amplitude-modulated by a sinusoid of swept angular frequency $\omega(t) = \omega_0 + \alpha t$, where t is time as measured from the beginning of the frequency sweep, ω_0 is the initial angular frequency, and α is the frequency-sweep rate. Suppose that the light reflected back to the input end of the optical fiber is fed to a photodetector, the output of the photodetector is mixed with a replica of the modulating sinusoid, and the output of the mixer is low-pass-filtered so as to retain only the difference-frequency mixer output. It can be shown that the resulting output signal is given by

$$S_{\text{out}}(t) = \sum_{n=1}^{N} B_n \cos\left[\tau_n(\omega_0 + \alpha t)\right]$$

where B_n is proportional to the amplitude of the reflection from the nth sensor and τ_n is the round-trip propagation time for the optical signal traveling from the input end to the nth sensor and back to the input end.

Thus, the output-signal component representing the reflection from the nth sensor is a sinusoid of amplitude B_n and frequency $\alpha\tau_n$. By taking the Fourier transform of $S_{\text{out}}(t)$, one can obtain its frequency spectrum and thereby extract the amplitude of the reflection from each sensor. Incidentally, the measured frequency of each component can be used to refine the estimate of the round-trip propagation delay for each sensor.

This work was done by George F. Lutes and Xiaotian S. Yao of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Systems category,* ***or circle no. 192*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

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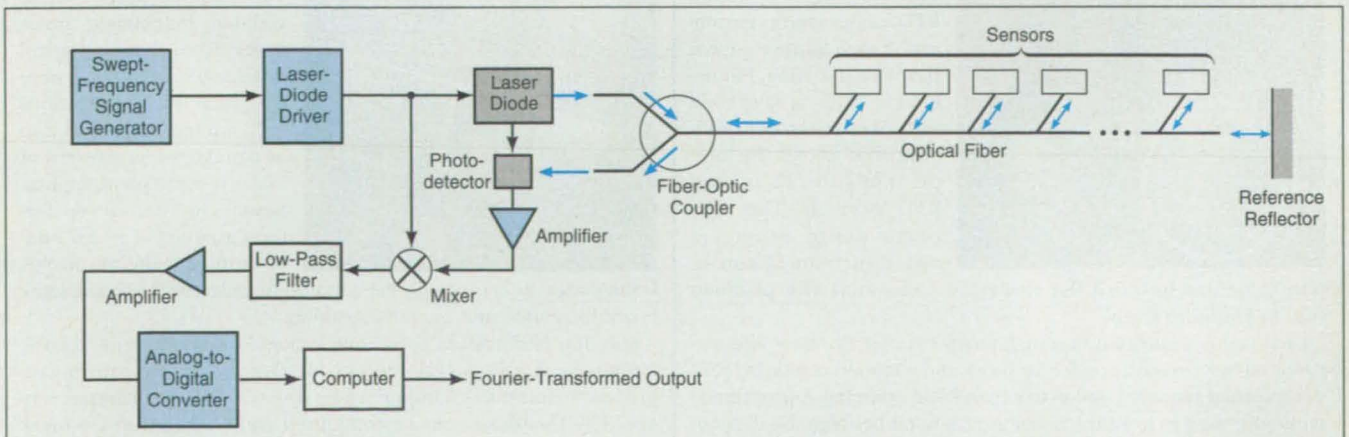


The **Propagation Delays of the Reflections** from the various sensors along the optical fiber result in differences between the phase of swept-frequency modulating signal and the phases of the modulations in the reflections. These phase differences are accompanied by frequency differences that can be exploited to identify and measure reflections from individual sensors.

SICK Optic-Electronic, Eden Prairie, MN, offers a line of **inductive sensors** that includes inductive proximity, magnetic proximity, and magnetic cylinder sensors featuring noncontact operation. The inductive proximity sensors, designed to detect metallic objects, come in shielded and non-shielded versions with shielded maximum sensing ranges to 15 mm and non-shielded ranges to 60 mm. Housings in ABS plastic, brass, and stainless steel come in threaded cylinder, smooth barrel, or cubical shapes.

The magnetic proximity sensors, in brass or plastic housings, offer sensing distances to 70 mm and can detect magnetic objects through non-magnetizable materials. Magnetic cylinder sensors are designed for position sensing in pneumatic cylinders. Fully electronic, they detect any magnetic ring in the piston through aluminum, brass, or stainless steel housing walls.

For More Information Circle No. 736

The CRX-3D microtomography **x-ray inspection system** from CR Technology, Laguna Niguel, CA, generates slice-by-slice 3D images of integrated circuits, components, hybrids, and other devices, bringing out hidden properties or defects. Faults detected include miswires, opens, shorts, and voids in flip chip, fine pitch, and BGA packages. The x-ray sources offer levels to 160 Kev and focal spot sizes less than 2 microns.

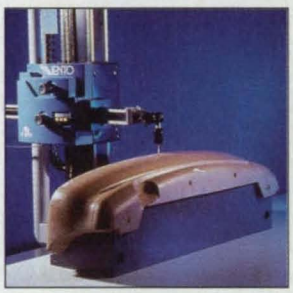
The system's holding fixture rotates the component through 360° while the imaging camera takes individual video frames. The software then uses the digitized images to reconstruct the interior of the component and allows the user to view it from multiple perspectives. The system comes with a tomographic indexing stage, image processing computer, and a 17" SVGA monitor.

For More Information Circle No. 726

The OG Series **photoelectric sensors** from efector, Exton, PA, feature automatic microprocessor setup in an 18-mm body size. The sensors are available with an infrared LED or laser diode light source. Infrared LED units are available as thru-beam pairs, as retroreflective sensors with polarizing filters, and as diffuse reflective models; laser models are available in three thru-beam versions, two retroreflective versions, and a diffuse reflective version.

The sensor bodies are molded as single units, including windows for LEDs and pushbuttons. They feature a variety of ranges and minimum target sizes and are available as three-wire DC units. Installation and alignment of the sensors is achieved with a mounting bracket and right-angle mirror adapter.

For More Information Circle No. 733



DEA-Brown & Sharpe, North Kingstown, RI, offers the VENTO high-speed direct computer-control **horizontal-arm measuring machine** that performs dimensional inspection of thin-walled parts such as automobile parts and subassemblies; dimensional inspection of prismatic parts; automatic and manual verification of freeform surfaces; continuous scanning operations for die and mold copying; and marking-out operations.

It has a measuring range of: X-axis 3000 to 12,000 mm; Y-axis 1400 to 1600 mm; and Z-axis 2000 to 2400 mm. Dual opposing machines can work together to cover larger areas. The machine is available in console and runway configurations. It can be equipped with PC-DMIS™ for Windows geometric measurement software, and comes with various electronic touch trigger and analog probes, heads, and automatic probe changers.

For More Information Circle No. 729

The Series 200 wire-wound RTD **temperature sensors and transmitters** from Burns Engineering, Minnetonka, MN, is available with Windows-based software that allows the user to configure their own RTD assembly. The wire-round design features a coil suspension construction technique in which the element is coil-wound with platinum wire to minimize stress.

Each coil is suspended in a high-purity ceramic insulator and surrounded by a ceramic powder for shock and vibration resistance without affecting the coil's ability to expand and contract. A proprietary method is used to form the metallurgical bond between the element leads and the internal sheath leads.

For More Information Circle No. 730

The Schaevitz™ LVIT-Z **linear variable inductance transducer** from Lucas Control Systems, Hampton, VA, were designed for applications with limited space and can be configured for a variety of linear measurement applications. The transducer features accuracy of ±0.5% nonlinearity over the full stroke. It integrates the sensor with the conditioning electronics on the same board for unit-to-unit interchangeability.

The unit features DC in-DC out, ratiometric, unipolar or bipolar outputs, and a duty cycle output for direct interface with microprocessor controllers. Output can be scaled to 90% of the input voltage. The transducer can be configured and packaged to customer requirements.

For More Information Circle No. 735

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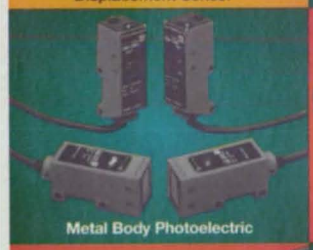
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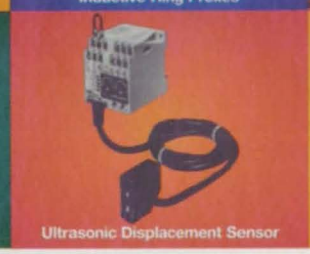
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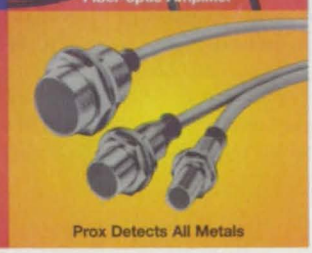
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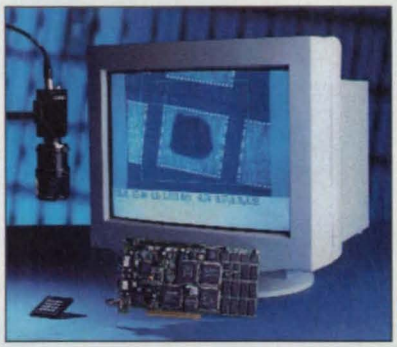
For More Information Circle No. 514

Cambridge AccuSense, Shirley, MA, has announced the AVS-Universal Series **thermistor-based transducers** that measure ultra-low air velocities covering a range from 0-100 fpm full scale to 0-1000 fpm. The output is linear with velocity. The transducers feature a standard response time of about 100 ms, accuracy of ±3% of full scale at room temperature, and solid-state construction.

A bi-directional version provides a positive or negative reading, depending on airflow direction. The unit is powered by 12-24V DC or AC, with output choices of 0-5V, 0-10V, or 4-20mA. Mounting hardware is included, and the units are housed in black, anodized aluminum with a 12.5" stainless steel probe.

For More Information Circle No. 731



Cognex Corp., Natick, MA, offers the Cognex 8000 Series™ **machine vision system** that features PatMax™ image analysis software. The 8000 Series hardware platforms plug directly into the PCI bus of standard Pentium MMX™ computers. The series includes products ranging from the 8100 basic model to the 8400, which incorporates a digital signal processor.

The PatMax software locates and inspects objects, features, and wafer and die patterns that change the way machine vision systems work. It can detect if pieces of the image are missing or if there are extraneous pieces present. For semiconductor and electronics applications, the software can locate and align 300-mm semiconductor wafers before probing, metrology, inspection, and bonding.

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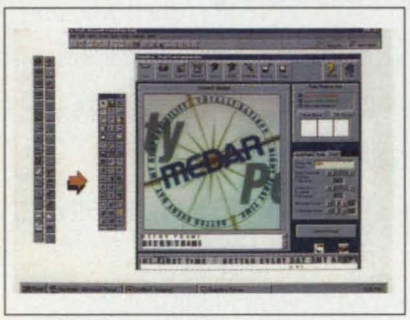

VisionBlox 2.1 **machine vision software** from Integral Vision, Farmington Hills, MI, features optical character verification and polar unwrap tools. The software is added into Microsoft's Visual Basic or Visual C++ programming environments, and allows users to acquire and grab live images with only two lines of code. The 32-bit software can be paired with a PCI frame grabber for image processing.

The program includes a Read Tool that verifies properly printed text in an image and an Unwrap Tool that unwraps a donut-shaped region of an image so the software can perform character verification or recognition.

For More Information Circle No. 728

Banner Engineering Corp., Minneapolis, MN, has introduced the Q45U Series **ultrasonic sensors** that are available in switched (digital) or analog versions. The 12-24V dc piezoelectronic units feature microprocessor-controlled, pushbutton setup of sensing limits from 100 to 1400 mm. A long-range model allows sensing from 25 to 390 mm.

LEDs continuously display programming and operating status, as well as the relative position of the target within the sensing window. Program storage cards allow window limit programs to be set and stored on circuit cards that slide into the units. The sensors can be wired directly to an external switch, controller, or computer to set window limits. Parallel microprocessors provide immunity to electrical and acoustic noise.

For More Information Circle No. 725

Cherry Electrical Products, Waukegan, IL, has introduced the HE-6150/6151/6152/6154 Hall Effect **geartooth sensor modules** that directly sense rotating ferrous gear-type targets such as power transmission gears and gear-based shaft encoders. They can sense a range of tooth sizes and airgaps, and are small enough to be used in space-constrained applications.

The modules deliver a digital output signal and do not require additional signal processing or external electronics. They are designed for installation with the major axis of the module perpendicular to the direction of target rotation. The HE-6154 can be mounted with any degree of rotation about its major axis; the other modules include provisions for mounting at the preferred angle.

For More Information Circle No. 732

Gordon Products, Brookfield, CT, has introduced the Model PC150 and PCA150 flat pack **capacitive sensors** that generate a low-power capacitive field to detect any material with a dielectric constant higher than 1 (air). They feature a 5.75" square internal sensing element, which allows detection of low-density materials. Both models are provided in a shielded housing for mounting on grounded metal surfaces.

The Model PC150 has both NPN and PNP, switched outputs, and is available in a normally open or normally closed configuration. The PCA150 has an analog output that delivers a linear DC voltage of 1-6 VDC that varies in proportion to target capacity. Both models feature operating voltage of 10-30 VDC with operating current of 12mA.

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GaAs-JFET-Based Multiplexers for Readout of VLWIR Detectors

A prototype circuit has functioned properly at a temperature of 4 K.

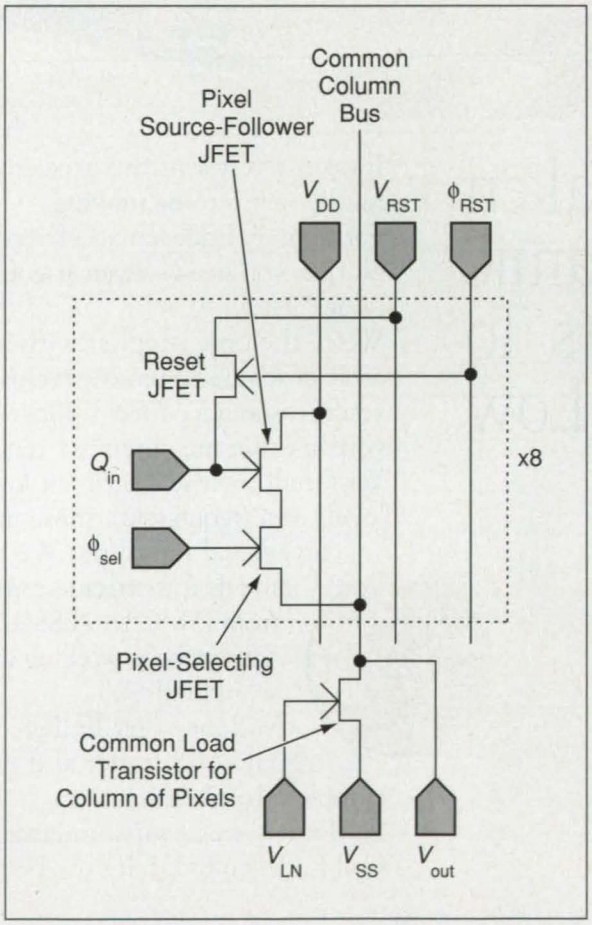
NASA's Jet Propulsion Laboratory, Pasadena, California

Integrated-circuit multiplexers based on gallium arsenide junction field-effect transistors (GaAs JFETs) are undergoing development for use in reading out signals from arrays of very-long-wavelength infrared (VLWIR) detectors. To minimize thermally induced electronic noise, electromagnetic interference, and microphonics in future infrared-sensing instruments, it will be necessary to eliminate long connecting wires between infrared detectors located on cold heads and readout circuits located in warmer compartments; to do this, one must place the readout circuits in immediate contact with the infrared detectors at the detector-operating temperatures, which are typically <10 K. To be suitable for VLWIR-detector applications, readout circuits must not only be capable of operating at low temperatures but must also feature low noise, moderately low input capacitances, very low input bias currents, and low power dissipation.

The selection of GaAs-JFET-based integrated circuits for these purposes was prompted by the following considerations:

- The performances of bipolar-silicon-transistor circuits and silicon-JFET circuits at such low temperatures are severely degraded by charge-carrier freezeout. Silicon metal oxide/semiconductor field-effect transistor (MOSFET) circuits can operate at temperatures of a few K, but at these temperatures, they exhibit excessive noise and other undesired characteristics.
- Discrete GaAs JFETs had previously been found to perform well at 4 K.

N-channel GaAs JFETs and associated circuit elements designed especially for cryogenic operation can be made immune to charge-carrier freezeout. The fabrication of these devices includes the use of highly isotropic $HF:H_2O_2:H_2O$ etchants in an etch-back technique for definition of gates and isolation of mesas. The isotropy of the etch eliminates sharp edges, thereby reducing edge electric fields, with consequent reductions in gate leakage currents.



This **Abbreviated Schematic Diagram** illustrates one of eight cells, plus common column circuitry common to all eight cells, of a prototype circuit for reading out an 8 × 1 array of VLWIR detectors.

A prototype GaAs-JFET-based integrated-circuit multiplexer for readout of an 8 × 1 linear array of VLWIR detectors was designed and fabricated. Each cell of this circuit (see figure) corresponds to one pixel and its VLWIR detector. In use, the pad marked "Q_{in}" would be connected to the VLWIR detector. As the detector integrated photogenerated electric charge, the voltage on the detector would change, and this voltage (the input voltage) would be applied to the gate of the source-follower JFET. The common load transistor at the bottom of the column would be biased at gate potential V_{LN} to form a current source. When clock potential ϕ_{sel} went high, the pixel-selecting transistor in the affected pixel would turn on, connecting the pixel source-follower JFET to the current source via the common column bus; the resultant voltage on the bus would equal the input voltage plus a fixed offset voltage. The pixel would then be reset by use of fixed reset potential V_{RST} under control by clock potential ϕ_{RST}. The foregoing process would be repeated, clocking through each of the eight pixels in turn, to sequentially read out all eight detectors.

In a preliminary test at 4 K without any detectors attached, the prototype circuit functioned properly and satisfied the requirements for low noise, low input bias current (as a result of low gate leakage), and low power dissipation. The leakage current was found to be <1 fA. When the circuit was biased at a common load current of 10 μA, the low-frequency noise was dominated by a component proportional to the reciprocal of frequency ($1/f$ noise) and was of the order of 1 $\mu V/Hz^{1/2}$ at a frequency of 1 Hz.

This work was done by Thomas Cunningham and Mike Fitzsimmons of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Circuits category,* ***or circle no. 103*** *on the TSP Order Card in this issue to receive a copy by mail (\$5 charge).*

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For More Information Circle No. 517

Electronically Switchable Bragg Gratings (ESBGs)

A new microdroplet liquid crystal/polymer composite material offers high efficiency, switchable holograms for laser beam steering, dynamic focus lenses, and control of fiber optic signals.

Foster-Miller, Inc., Waltham, MA

The use of holograms, Bragg gratings, and diffractive optical elements is extensive in photonic systems of all kinds, including displays, spectrographic instruments, optical interconnects, and optical fiber communications links. A new materials technology now permits high-quality Bragg holograms to be realized in an electronically switchable form, transforming passive holograms into active switches. A wide variety of novel applications is emerging.

The new material, a holographic polymer/liquid crystal composite, was invented at the USAF Wright Laboratory by employees of Science Applications International Corporation (SAIC), originally for the purpose of protecting pilots from laser beams. The Foster-Miller Photonics Division, under the support of a NASA SBIR program monitored by Marshall Space Flight Center (solicitation year 1993), has worked closely with SAIC and the Air Force to apply this material for a variety of commercially promising purposes, including switchable focus lenses and fiber optic switches and filters.

In the ESBG process shown in Figure 1, a volume hologram is recorded by polymerizing a photosensitive liquid solution of seven ingredients including liquid crystal, prepolymer, solvents, and photoinitiators by exposure to interfering blue-green laser beams. This results in a permanent, high-diffraction-efficiency photopolymer Bragg grating, whose microstructure is formed by alternating layers of spatially distributed ≈30-nm liquid crystal droplets interspersed with pure polymer. Transmission gratings with periods of 0.4 μm or less can easily be recorded, resulting in large diffraction angles for visible/near-IR wavelengths. Initially, the liquid crystal directors inside each slightly elongated droplet are aligned along the long axis. By applying an electric field to the film, the liquid crystal directors can be rotated inside the droplets, varying their effective refractive index, until the polymer host index is exactly matched. Then the grating effectively vanishes, turning the Bragg diffraction off, and making the previous photopolymer hologram into a film of transparent plastic.

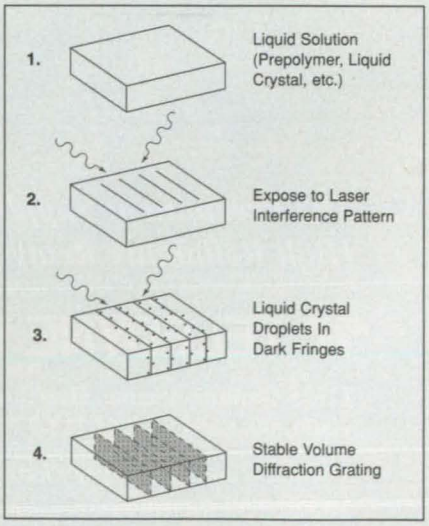

Figure 1. **One-step Holographic Process** to make ESBG.

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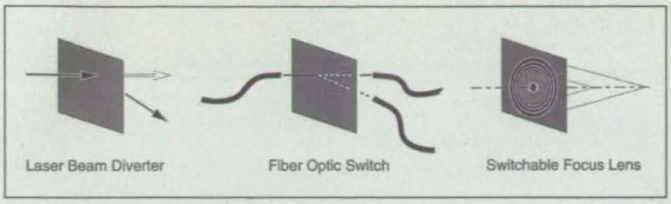

Figure 2. **Free-space ESBG Devices.**

The result is an electronically switchable Bragg grating (ESBG). In practice, first-order 99-percent diffraction efficiencies can be switched to less than 0.3 percent, for an on/off ratio of 25 to 30 dB, and it appears likely that a 40-dB dynamic range will be achieved in the near future. The material has intrinsically low scattering and absorption, so it has been possible to stack four or more layers of ESBG film for multiple diffraction. In addition, the usual millisecond speeds of nematic liquid crystals in their bulk form become substantially faster due to encapsulation in microdroplets; 20-μs switch-on times and 40-μs off times have been recorded. However, electric fields to switch ESBG films must be larger than for simple liquid crystals, about 4 V/μm for films 5 to 20 μm thick.

Figure 2 shows three basic applications. A switchable transmission hologram ESBG steers a laser beam through a fixed angle. A fiber optic switch version couples to laser signals in fibers. More complex holograms such as lenses can also be recorded and switched.

Lens applications are widely useful. ESBG holographic lenses show the strong chromatic dispersion characteristic of diffractive lenses. In this case, however, the focus property can be electronically controlled, promising a new basis for devices such as an imaging spectrometer with no moving parts. Another technology demonstrated by Foster-Miller under SBIR sponsorship is an optical multilayer disk pickup head which uses ESBG films in the optical lens system to maintain a small spot size regardless of the depth of the read-plane.

The most commercially promising applications may be in the fiber optic telecommunications industry. Increased demand due to Internet and other traffic has accelerated installation of multiwavelength networks conveying many high-bandwidth signals on one optical fiber. Better methods for selecting signals of different wavelengths, and for switching signals from one fiber to another, are needed. Because of the geometric flexibility of ESBGs, not only free-space beam steering and lenses but also waveguide and optical-fiber-based films have been demonstrated at Foster-Miller. For example, Figure 3 shows a fiber-coupled Bragg grating that can select to retain or drop one wavelength channel from a fiber transporting 8 or 16 such signals spaced very closely, 0.8 nm apart at the communications wavelength of 1550 nm. ESBG technology also appears to be very inexpensive to manufacture, an important factor in extending broadband fiber optics to the office building and the home.

This work was done by Dr. Lawrence Domash and coworkers at **Foster-Miller, Inc.**, *195 Bear Hill Road, Waltham, MA, working in collaboration with Dr. Richard Sutherland and coworkers at Science Applications International, under an SBIR contract monitored by* **NASA's Marshall Space Flight Center.** *For more information, call (617) 684-4164.*

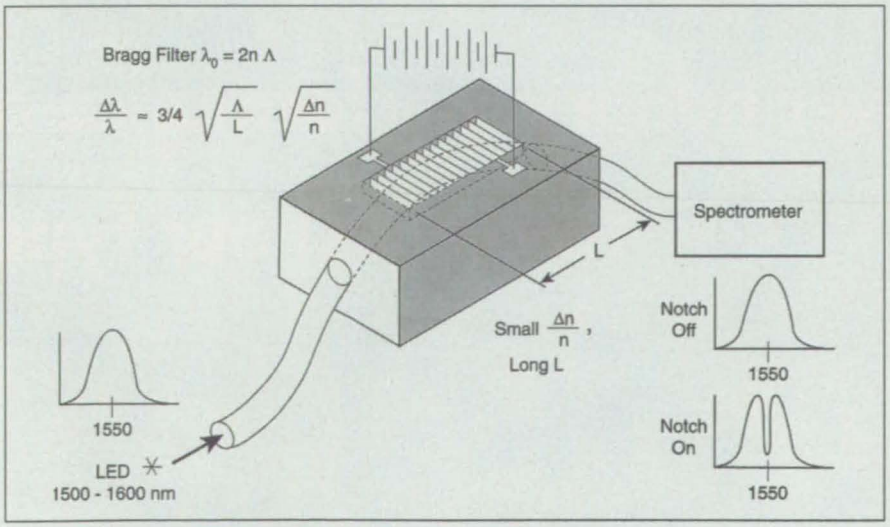

Figure 3. **Switchable Fiber-coupled Bragg Filter.**

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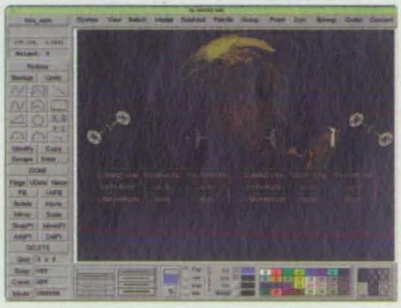

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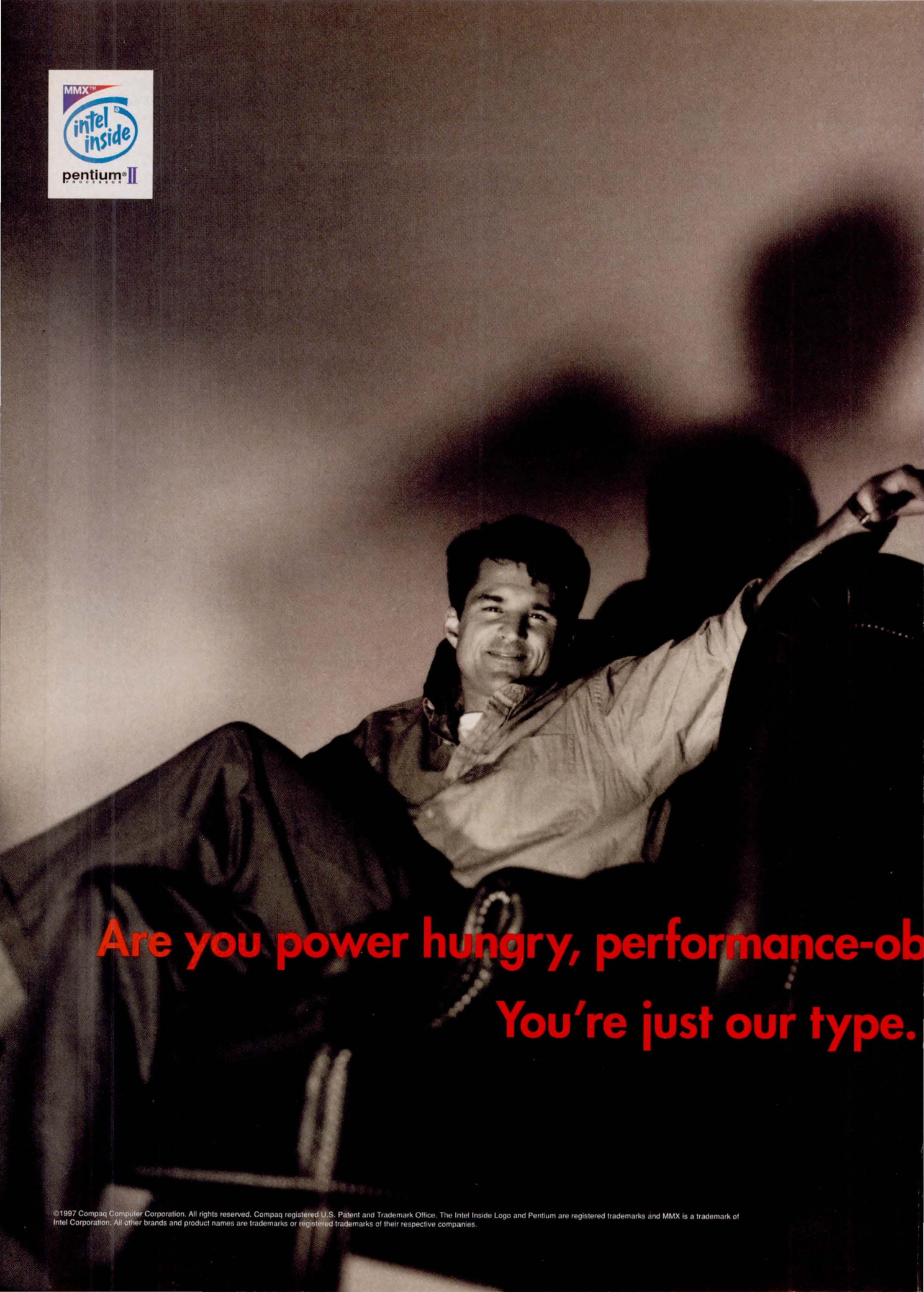

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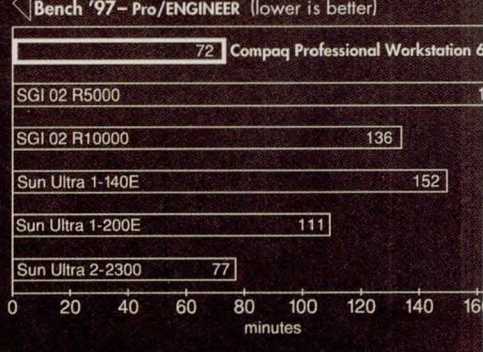

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For More Information Circle No.

Telerobot Control for Microsurgery

Hand movements are repeated on a smaller scale, without tremor.

NASA's Jet Propulsion Laboratory, Pasadena, California

A telerobotic system for microsurgery has been designed to reproduce the motions of a surgeon's hand on a more precise scale and with smoother motion than previously possible. This system can be used for surgeries on the eye, brain, ear, and face and in the repair of fine blood vessels and nerves. The surgeon holds a handle attached to a master robot arm and moves it to specify the motions of a surgical instrument on the slave robot arm. The surgeon's hand motions are scaled down and filtered to enable precise surgical-instrument positioning without tremor (see figure).

The master arm measures the position of the model-tool position in 6 degrees of freedom (DOF) and reflects forces with 3 DOF. It measures input position in increments of 0.001 in. (25.4 μm) in translation and 0.07° in rotation. The slave arm has 6 DOF and responds with movements in increments of 20 μm. The system provides several modes of control, and can be switched easily between modes.

The system includes the following subsystems:

- The mechanical subsystem, including motors, encoders, gear and cable drive mechanisms, and robot links and joints;
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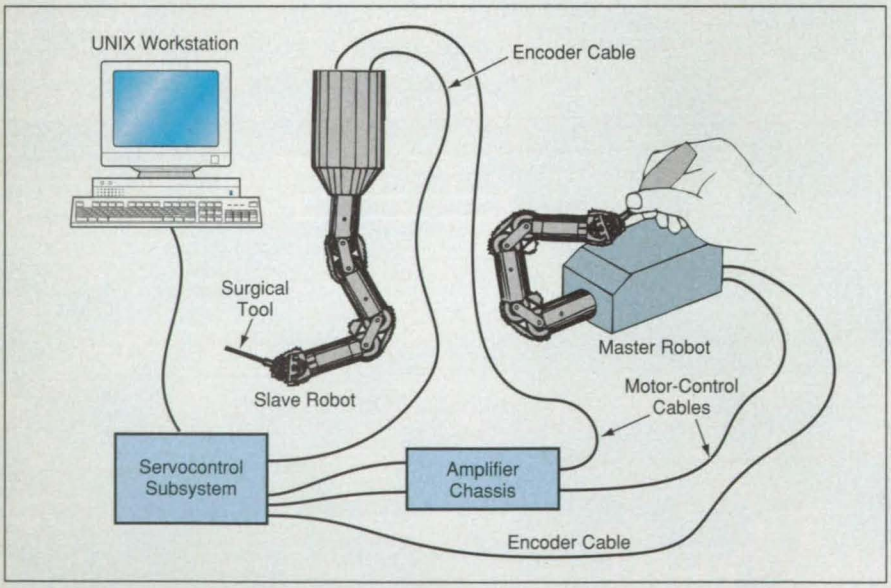
- The servocontrol subsystem, including a servocontrol circuit board, software, communication electronics, and shared memory software; and
- A software subsystem that resides partly in a UNIX host computer and partly in the servocontrol subsystem and that implements algorithms for the forward and inverse kinematics of the slave robot, algorithms for demonstration modes of control, and a graphical user interface.



Small Movements of a Surgeon's Hand are scaled down to even smaller movements of a surgical tool at the tip of the slave robot arm. The system removes hand tremor from the control signal, so that only the desired movement is reproduced in miniature by the slave robot arm.

This work was done by Timothy Ohm, Hari Das, Guillermo Rodriguez, Curtis Boswell, Paul Schenker, and Ed Barlow of Caltech; Eric Paljug of McKinsey & Co., Inc.; and Steve Charles of MDS, Inc., for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Systems category,* ***or circle no. 107*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Technology Reporting Office
JPL
Mail Stop 122-116
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-2240

Refer to NPO-19823, volume and number of this NASA Tech Briefs *issue, and the page number.*

Hydrogen-Fire-Detector Calibration Unit

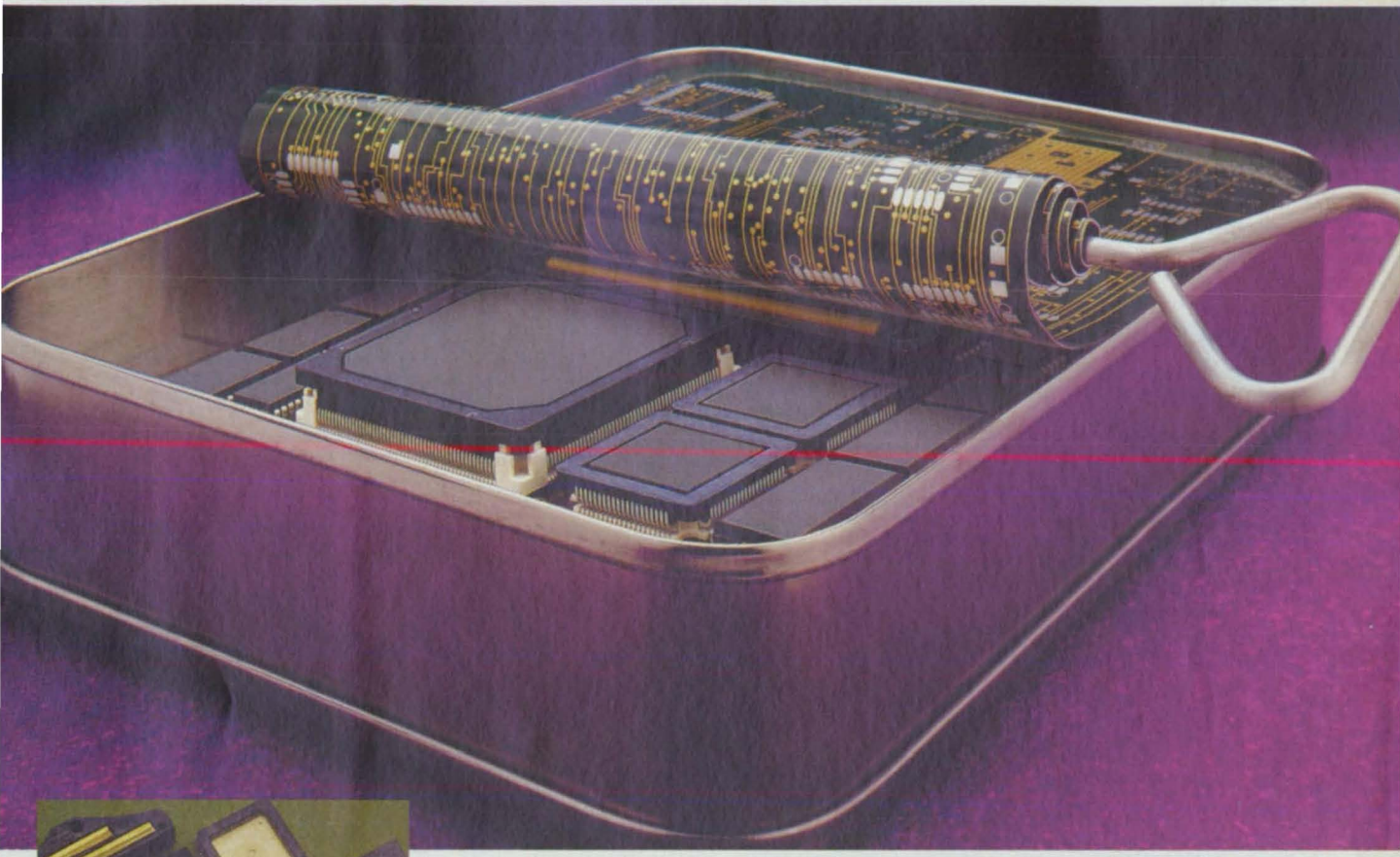
A tabletop unit contains an ultraviolet source and calibration circuits.

John F. Kennedy Space Center, Florida

A microprocessor-controlled, tabletop apparatus has been developed for use in testing ultraviolet-sensitive alarm circuits that detect hydrogen fires at various distances. The apparatus includes a krypton discharge lamp that emits ultraviolet light of about the same intensity and in the same wavelength range (180 to 240 nm) as observed in hydrogen fires that were previously used to test the hydrogen-fire detectors. By eliminating the need to test with hydrogen fires, the apparatus obviously contributes to overall safety.

The apparatus includes a bracket that holds the hydrogen-fire detector to be tested in the required geometric relationship with respect to the krypton dis-

How to beat the squeeze in today's tight design environments.



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charge lamp. The main functional characteristic of the apparatus is that it provides ultraviolet light in the required spectral range at a stable, repeatable, and uniform intensity across the face of an ultraviolet-sensitive detector tube in the fire detector. The necessary uniformity of intensity is provided by reflective and diffusive optical elements associated with the lamp.

Repeatability and stability of intensity are provided via microprocessor control of the positions of adjustable optical elements and by electronic feedback control of the power supplied to the lamp. The intensity feedback is obtained from an ultraviolet-sensitive photodetector near the lamp. A spinning chopper wheel modulates the light seen by the detector to enhance the performance of the feedback system. In response to the feedback signal, the microprocessor adjusts the power supplied to the lamp to maintain the intensity at a value selected by the technician.

Electronic control of the power supplied to the lamp can vary the intensity by a factor no larger than about 2, but a factor of about 100 is required for the complete range of tests to simulate the signals from a standard hydrogen fire at distances from 10 to 64 feet (3 to 19 m). To provide the necessary increments of intensity over this large dynamic range, the apparatus is also equipped with a microprocessor-controlled iris and a microprocessor-controlled filter wheel that contains neutral-density filters of different densities.

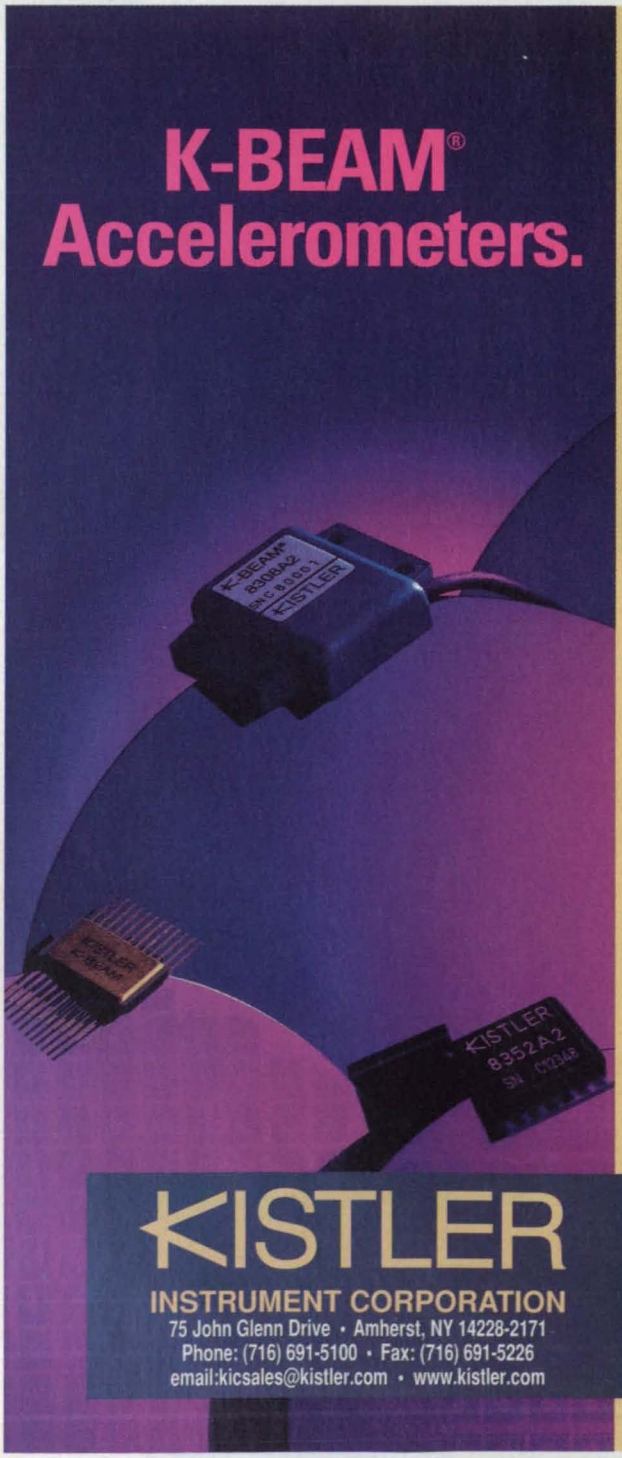
After startup, a liquid-crystal display unit on the apparatus presents three options to the technician; (1) functionality check, (2) specification check, or (3) alarm-time-versus-distance measurement. The functionality check involves determining whether a power relay within the unit is operational, turning on the lamp, and determining whether the ultraviolet light supplied by an internal lamp can trigger the alarm function in the hydrogen-fire detector under test.

The specification check includes a calibration needed to determine whether a hydrogen-fire detector satisfies its performance requirements. During a specification check, the apparatus projects ultraviolet light at known intensities into the fire detector to determine whether the minimum- and maximum-sensitivity requirements are satisfied.

The alarm-time-versus-distance measurement is carried out by projecting ultraviolet light into the fire detector at an intensity representative of that of a standard hydrogen fire located well within the alarm distance of the detector. The time taken to alarm is then measured, and the detector is allowed to come out of an alarm state. The intensity of ultraviolet light is then dropped to correspond to a slightly larger distance, and the alarm time measured again. This process is repeated until the alarm time is greater than 30 seconds. This measurement provides a characterization of the performance of the fire detector versus the distance to a standard hydrogen fire.

This work was done by Gregory A. Hall and William E. Larson of **Kennedy Space Center** *and Robert C. Youngquist, John S. Moerk, William D. Haskell, Robert B. Cox, Jimmy D. Polk, Stephen J. Stout, and James P. Strobel of I-NET, Inc. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Systems category,* ***or circle no. 108*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

This invention has been patented by NASA (U.S. Patent No. 5,561,290). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Kennedy Space Center; (407) 867-2544. Refer to KSC-11722.



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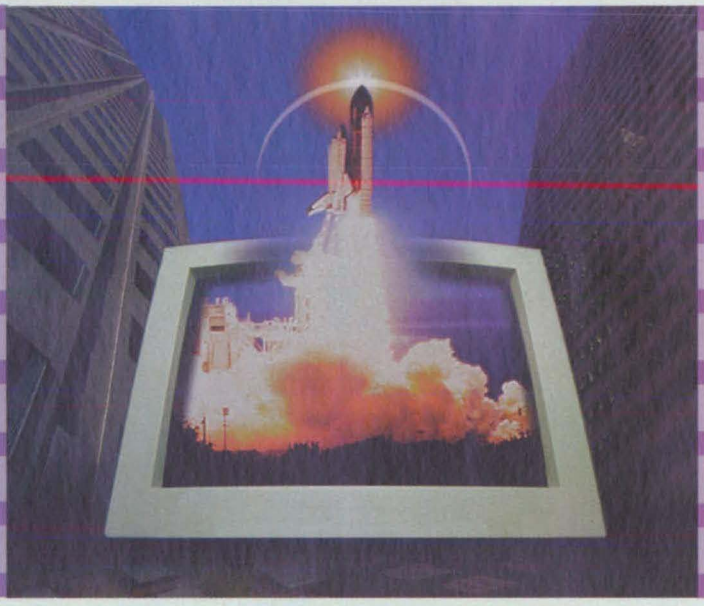

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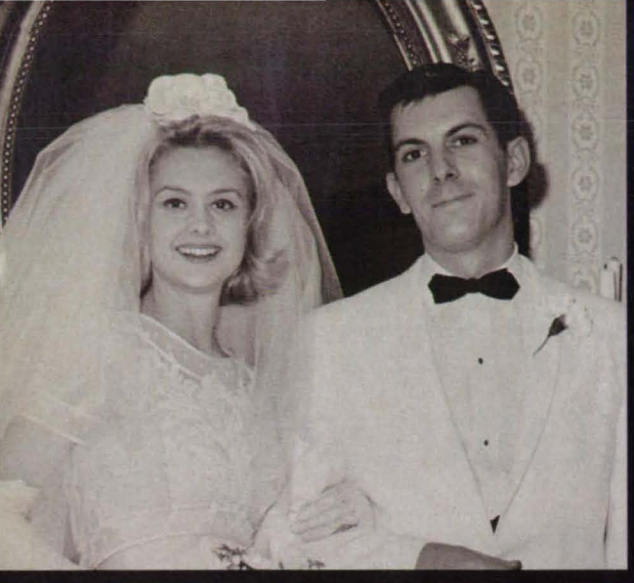

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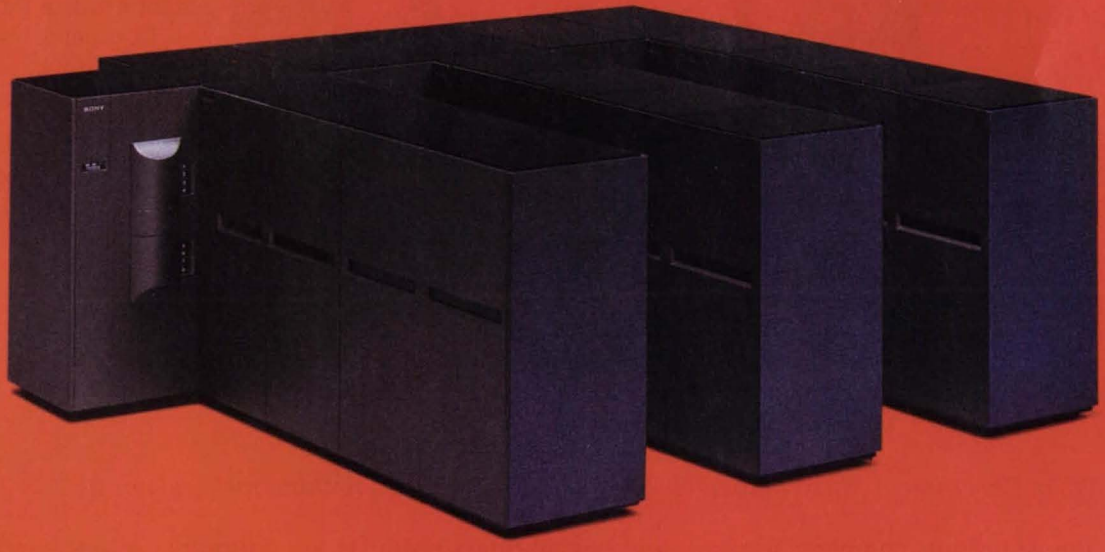

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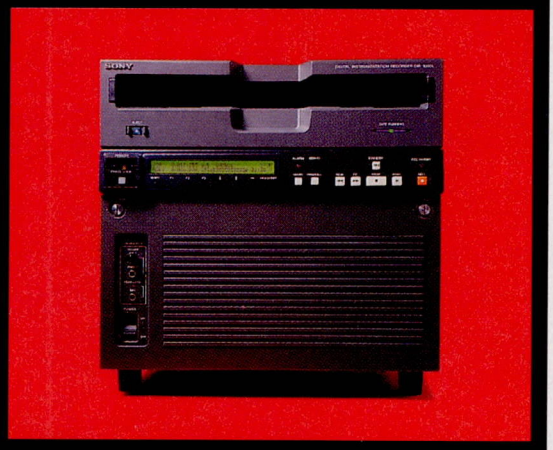

Large Scale Database Backup

ADI-1150 DIGITAL DATA RECORDER

One of the newest members of the Sony family, this unit delivers a sustained data rate of 15 MB per second over SCSI-2 Fast and Wide interface, combined with a maximum capacity of up to 52 GB of uncompressed data per cassette. The ADI-1150's impressive performance and favorable cost/performance ratio makes it the perfect fit for applications that range between our DIR and DTF drives. Also compatible with the PetaSite Mass Storage Library.

Digital Image Storage

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Our next generation DTF high performance computer peripheral tape drive is rich in family heritage, based on Sony's highly successful Digital Betacam® professional recording technology. The GY-2120 (pictured here) features a sustained transfer rate of 12 MB per second (up to 20 MB per second with compression) and storage capacity of up to 108 GB compressed on a single cassette. It has the ability to backup 100 GB of data in approximately an hour and a half, and is already setting the standard for high performance and reliability in a SCSI attached tape storage peripheral. It's also compatible with the PetaSite Mass Storage Library.

Automated Tape Libraries for Mass Storage

Remote Sensing

For More Information Circle No. 542

SONY

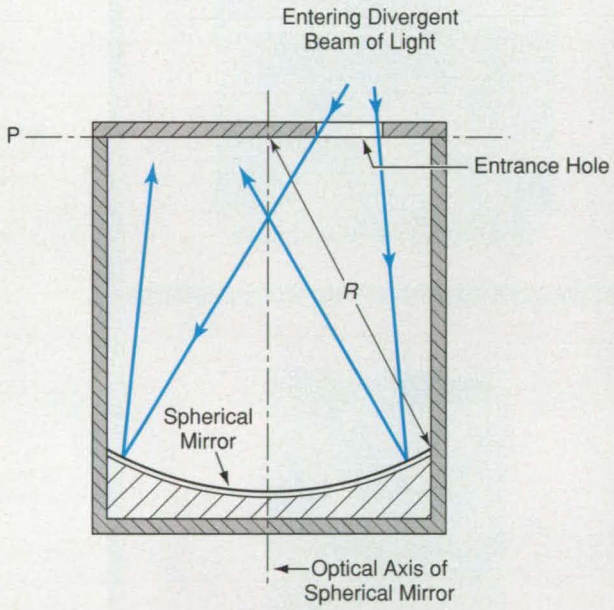
Better Cells for Multiple-Pass Absorption of Light in Gases

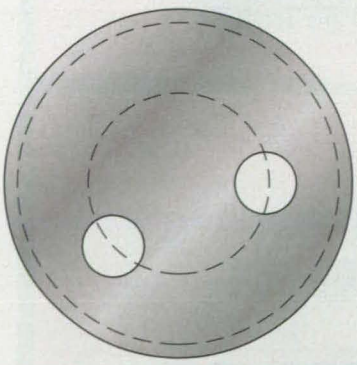
These cells overcome some of the limitations of older multiple-pass absorption cells.

Ames Research Center, Moffett Field, California

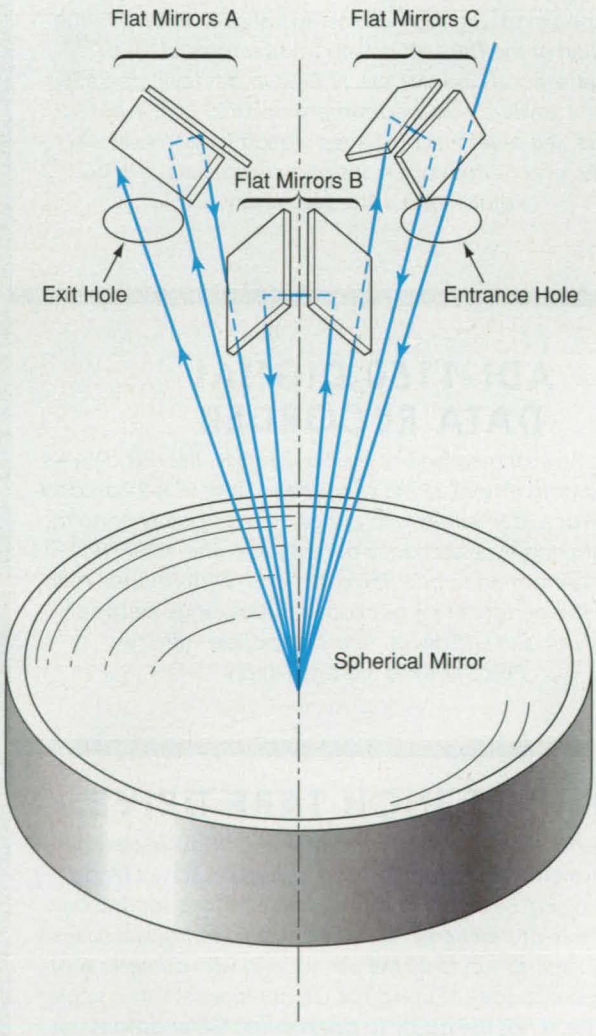
A new multiple-pass optical gas measurement cell has been developed that provides improved analytical accuracy and reduced size and cost, compared to older designs.

Optical sampling cells allow the measurement of light absorption in samples of gas, using the Beer-Lambert relation. Single pass cells are not difficult to manufacture, but the light path is too short for practical use with weak gas concentrations or with gases that have low absorption properties. In these situations, multiple-pass cells are used, providing for a longer path for the light to travel. However, accuracy of the light path is more difficult to control in



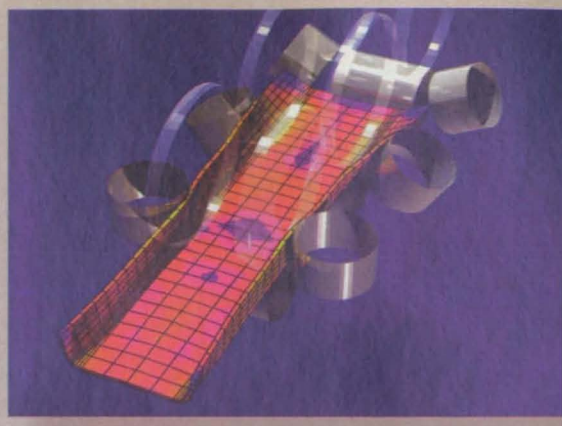


GENERAL OPTICAL SCHEME SHOWING INCOMING BEAM AND FIRST REFLECTION



OPTICAL SCHEME OF AN EIGHT-PASS CELL (Nonoptical Components Omitted For Clarity)

Multiple Passes of a Beam of Light through a cell are achieved by reflection between a spherical mirror and multiple pairs of suitably positioned and oriented flat mirrors. In comparison with older multiple-pass configurations, this one is less sensitive to misalignment and better able to accommodate a wide and/or divergent beam of light.



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multiple-path cells. Traditional multiple-pass optical cells with analytical levels of accuracy are relatively large, and need a bright, well-collimated light source for best performance.

The new design developed at the NASA Ames Research Center overcomes several of the limitations inherent in older gas cells, by combining a single spherical lens and two or more flat mirrors to extend the length of the light path.

The left part of the figure illustrates the principles of operation of the new design. A beam, or bundle, of light, which can be divergent, enters the entrance hole, and is reflected by a spherical mirror of radius R and focusing on a top cover on plane P and approximately height R above the spherical mirror. Without additional mirrors, the light beam would thus be focused on the top cover of the device. However, the light is not allowed to strike plane P. Instead, pairs of flat mirrors (one to three pairs would be typical embodiments) are placed near the entrance, and are positioned and oriented to redirect the beam to the spherical mirror. The positions and orientations of the flat mirrors are chosen to make the beam come to a focus between them, so that the central ray of the light beam is reflected back toward the center of the spherical mirror. The last flat mirror is arranged such that, after the final reflection from the spherical mirror, the light beam passes through an exit hole on the top cover. The exit hole is on the same plane as the entrance hole, but at a different azimuthal position on the top cover.

The right part of the figure illustrates the path followed by the central ray of the beam in an eight-pass cell based on this concept. The ray enters the cell (pass 1), and is reflected by the spherical mirror back toward the first of six flat mirrors (pass 2). Passes 3 through 7 are back and forth between the spherical mirror and the remaining five flat mirrors. After the last reflection from the spherical mirror, the ray leaves through the exit hole in the top cover (pass 8).

Unlike some older multiple-pass absorption cells, it is not necessary to use narrow, well-collimated beams of light with this design when only a few passes are necessary. This is due to the property of the combined spherical and flat mirrors' tendency to reduce stray light paths within the cell, thus reducing errors when calculating gas absorption values.

Another advantage of the new design arises from the need for accurate knowledge of the length of the optical path within the cell in order to compute the light absorption using the Beer-Lambert relation. The configuration of the mirrors in the new design makes it easier to manufacture cells with precisely known light-path lengths.

This work was done by Richard Pearson, Dana H. Lynch, and William D. Gunter of **Ames Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category, or* ***circle no. 115*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

This invention has been patented by NASA (U.S. Patent No. 5,459,566). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center; (415) 604-5104. Refer to ARC-13384.

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For More Information Circle No. 521

Optical Air Mass Flux Sensor for Aeroengine Monitoring and Control

A diode-laser-absorption sensor for simultaneous measurements of air density and velocity has achieved ±2-percent accuracy in an F-100 engine inlet.

Physical Sciences Inc., Andover, Massachusetts

Flight-qualifiable sensors for inlet air mass flux are desired for improved control of conventional aeroengine gas turbine power plants and variable-geometry, mixed-compression inlets of advanced flight vehicles. Optically based techniques are advantageous for inlet measurements, particularly in compressible flows, because they do not disturb the flowfield downstream of the measurement location. Under support from the NASA Dryden Flight Research Center (solicitation year 1992), a sensor using fiber optic beam transport and ultra-low-noise detection has been developed to obtain high-precision measurements of the O_2 density and Doppler shift, permitting rapid determination of the density-velocity product, or mass flow into the engine.

In the basic sensor configuration, a room-temperature diode laser, operating near 763 nm, is fiber-coupled and split into two signal and two reference channels. Fiber optic cables bring the signal channels to two launch modules, where the narrowband, tunable laser light is collimated and launched across the flow duct at opposing angles. The transmitted light is detected with a pair of Si photodetectors configured in a sensitive balanced detection system.

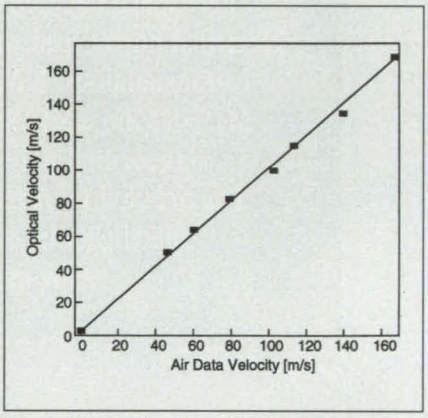

Figure 1. Example of Air Velocity Data.

Using the reference channels to account for common-mode laser amplitude noise, near shot-noise-limited absorption sensitivity is obtained, allowing the weak O_2 absorption lineshapes to be accurately recorded as the laser wavelength is rapidly swept across an isolated lineshape. The integral of this lineshape gives the O_2 density. The relative shift in frequency between the lineshapes recorded across the opposed paths gives a measure of the path-averaged gas velocity across the duct. The simultaneous measurements of density and velocity are combined with the known duct area to yield a measure of the integrated mass flux in the duct.

Extensive testing of the basic sensor in laboratory flows, full-scale aeroengine, and large-scale wind-tunnel test facilities has built a large, statisti-

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cally significant database of the sensor's performance in several flow environments. On a full-scale Pratt & Whitney F-100 aeroengine test, performed in a ground test at the NASA Dryden Flight Research Center, mass flux measurements with a precision and absolute accuracy of 1 to 2 percent over the full range of engine operating conditions were demonstrated.

Figure 1 is an example comparison of the diode laser's optical velocity measurement with a calibrated Pitot-static air probe. The range of velocities shown spans idle to full Mil-spec power conditions.

Commercial development of a version of this sensor for compressor stall/surge monitoring and possible control is being pursued with support from the AlliedSignal Engine Company. Additional support from NASA Dryden is developing a flight version of the sensor for installation and testing in a NASA F-18 test vehicle.

This work was done by **Physical Sciences Inc.**, *20 New England Business Center, Andover, MA 01810-1077, under a NASA SBIR contract monitored by* **Dryden Flight Research Center**. *For more information, contact Dr. Mark Allen, (508) 689-0003.*
DRC 096-07

Electrochemical Process for Treatment of Wastewater

The treated water is potable.

Lyndon B. Johnson Space Center, Houston, Texas

A prototype apparatus implements an electrochemical process for treatment of wastewater streams that contain various proportions of urine, laundry water, and bath water. The process comprises three sequential subprocesses; a batch electrolysis process followed by a batch electrodialysis process followed by a continuous-flow catalytic oxidation process (see figure). Each of the first two subprocesses removes a different group of contaminants and/or passes on partially reacted contaminants to the next subprocess. The electrochemical energy produced in the electrolysis subprocess results in oxidation of organic contaminants except organic acids. The electrodialysis subprocess removes organic acids and ions. The catalytic oxidation subprocess removes most of the remaining contaminants.

At the beginning of the process, a batch of wastewater (2.3 L in the case of the prototype apparatus) is transferred to a reservoir in the electrolysis section. The electrolysis subprocess takes 260 to 280 min and includes a foam-suppression preprocess: The wastewater is recirculated through the electrolysis section along one of two alternative paths depending on the time. Before electrolysis starts and during the first 30 min of electrolysis, water flows through a regenerable foam-suppression unit, then the electrolysis cell, and back to

the reservoir. This path reduces the concentration of foam-forming contaminants to tolerable levels. After 30 min of electrolysis, the path changes to bypass the foam-suppression unit.

The polarity of the voltage applied to the electrolytic cell is reversed once per minute to counteract the buildup of polarized ions near the electrodes and increase the concentration of reactants at the surfaces of the electrodes. The liquid being processed is recirculated through the electrolytic cell at a constant rate of 1 L/min. An oxidation/reduction-potential sensor indicates the end point of the electrolysis, which is defined as the point at which energy-utilization efficiency decreases during electrolysis. A gas-conditioning unit absorbs water vapor and chlorine produced by the electrolysis process. The total concentration of carbon in organic compounds ["total organic carbon" (TOC) for short] and the pH of the processed liquid are more than halved by the electrolysis process. Remaining organic materials are converted to low-molecular-weight organic acids that can be separated efficiently by electrodialysis.

After electrolysis, the water is transferred to a reservoir in the electrodialysis section. In the electrodialysis subprocess, an electric field causes ions to migrate through membranes, thereby concentrating the contaminants into a brine while forming a deionized product water that is relatively free of contaminants. The statuses of the brine and the product water are monitored (to determine the end point for electrodialysis) by use of electrical-conductivity meters. The brine is stored, while the deionized product water is moved on to catalytic oxidation.

In the catalytic oxidation subprocess, the TOC of the remaining contaminants is reduced to below 500 micrograms per liter — a level that satisfies NASA's specification for potable water. Oxidation byproducts (oxygen and carbon dioxide), are removed by a gas/liquid separator at the outlet of the catalytic oxidizer.

This work was done by James R. Akse of Umpqua Research Co. for **Johnson Space Center**. *For further information, access the Technical Support Package (TSP)* ***free online at www.nasatech.com*** *under the Physical Sciences category, or* ***circle no. 117*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*
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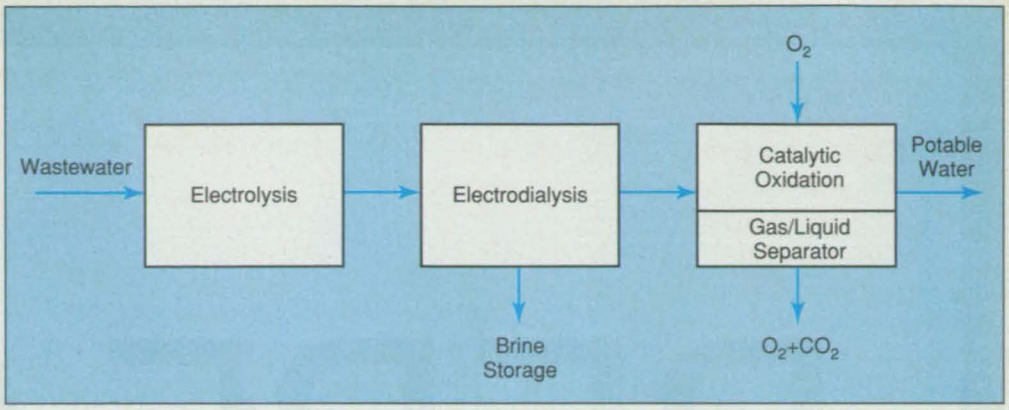

This **Electrochemical Water-Treatment Process** comprises three subprocesses, each of which plays an essential role in relation with the others.

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Bonding conditions are consistent with chemical properties and temperature limitations of substrates.

Lewis Research Center, Cleveland, Ohio

Strain gauges with improved adhesive bonding have been developed for use in measuring creep and stress-relaxation effects associated with aging in PMR-15 polyimide resin at test temperatures up to and even somewhat above the maximum use temperature of 371 °C. Even near the upper limit of test temperatures, the improved adhesive bonding provides secure attachment to substrates of both PMR-15 composites and titanium alloy 6242.

The development of these strain gauges and the improved adhesive bonding were necessitated by the limitations of previously available strain gauges. The best previously available adhesively bonded strain gauges could not withstand prolonged exposure to temperatures above 232 °C and were recommended for no more than 150 hours of operation at 280 °C. The adhesive in those gauges had to be cured at temperatures up to 42 °C above the intended test temperatures; some substrate materials, including PMR-15 composites, cannot withstand this much heating above test temperatures.

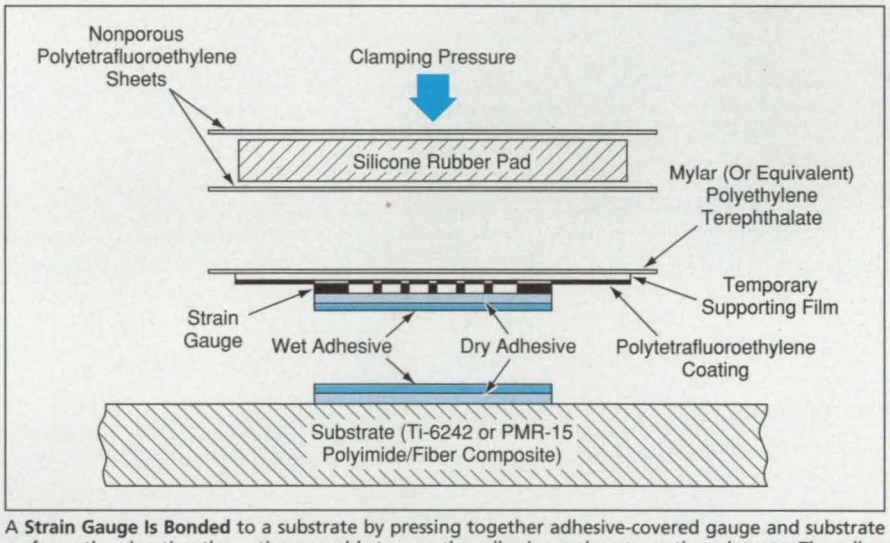
The improved bonding of the present strain gauges is achieved by use of a procedure and materials compatible with the cure chemistry and with the processing requirements for the substrate material. The maximum bonding temperature does not exceed the intended test temperature or the maximum substrate-fabrication temperature. Also, unlike standard previously available adhesively bonded strain gauges, the present strain gauges are not backed with permanent organic supporting films that must be bonded to the substrates; the present gauges are manufactured with temporary supporting films, and the gauges themselves, rather than the supporting films, are adhesively bonded directly to the substrates.

In the case of a PMR-15 substrate, the improved bonding procedure is initiated after the cure and before the postcure stage of the substrate-fabrication process. The adhesive is a slurry that is made by preparing a solution of poly(amic acid) in N-methyl-2-pyrrolidinone, then adding a partially reacted (imidized but not cross-linked) PMR-15 powder. The poly(amic acid) solution is used to obtain adequate flow and wetting of the substrate.

The gauge is cleaned by exposure to ultraviolet light and ozone. A first coat of adhesive is applied to the substrate and to the gauge face opposite the temporary supporting film, then this first coat is dried by heating to temperatures up to 205 °C. A second coat of adhesive is applied, then the gauge and substrate are clamped together (see figure) and heated according to the normal postcure schedule of 205 °C for 10 minutes followed by 316 °C for two hours.

In a test of the gauges and improved bonding, a gauge remained bonded to a PMR-15 composite substrate and exhibited adequate resistance to creep after aging for a month at 316 °C. The present gauge/adhesive system has also been shown to withstand thermal cycling up to 364 °C and to withstand maximum temperatures up to 400 °C for short times.

Though the adhesive bonding system has been demonstrated on PMR-15 resin and titanium-alloy substrates, bonding to PMR-15 composites and to other polymeric and metal substrate materials should be possible. For bonding to other polymeric substrates, the adhesive system would be modified by replacing the poly(amic acid) and the PMR-15 powder with materials more similar to, and/or more compatible with, the substrate material.



A Strain Gauge Is Bonded to a substrate by pressing together adhesive-covered gauge and substrate surfaces, then heating the entire assembly to cure the adhesive and postcure the substrate. The adhesive is formulated to be compatible with the cure chemistry, processing requirements, and temperature limitation of the substrate.

This work was done by Gary D. Roberts, Kathy C. Chuang, and J. Michael Pereira of **Lewis Research Center**; *Christopher Rabzak of NYMA, Inc.; and Douglas T. Jayne of Ohio Aerospace Institute. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category,* ***or circle no. 121*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

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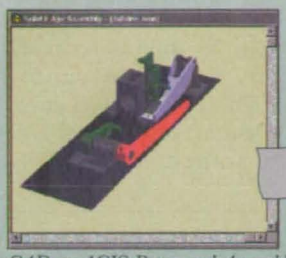

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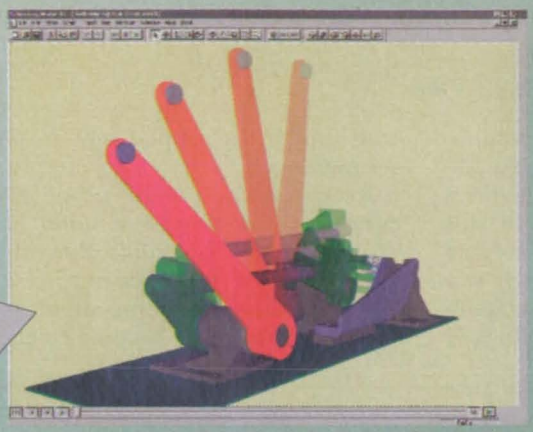

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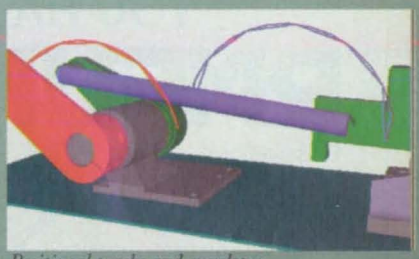

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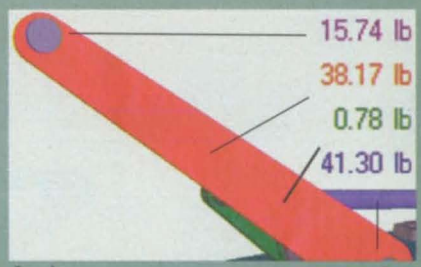

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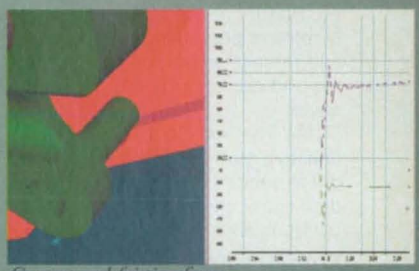

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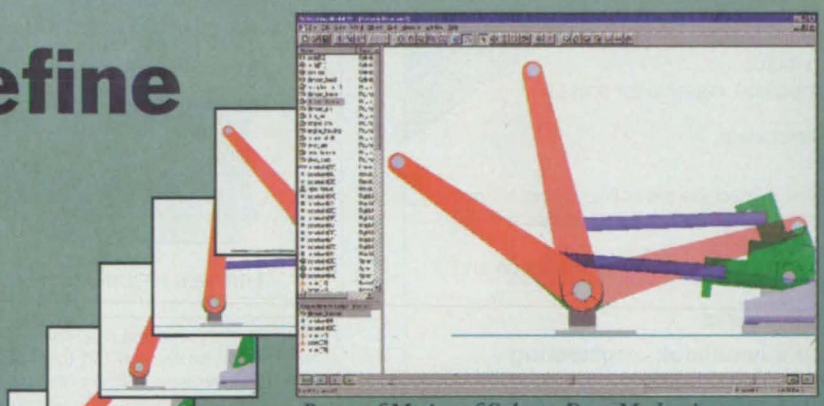

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Modified CVI Process for Making SiC/SiC Composites

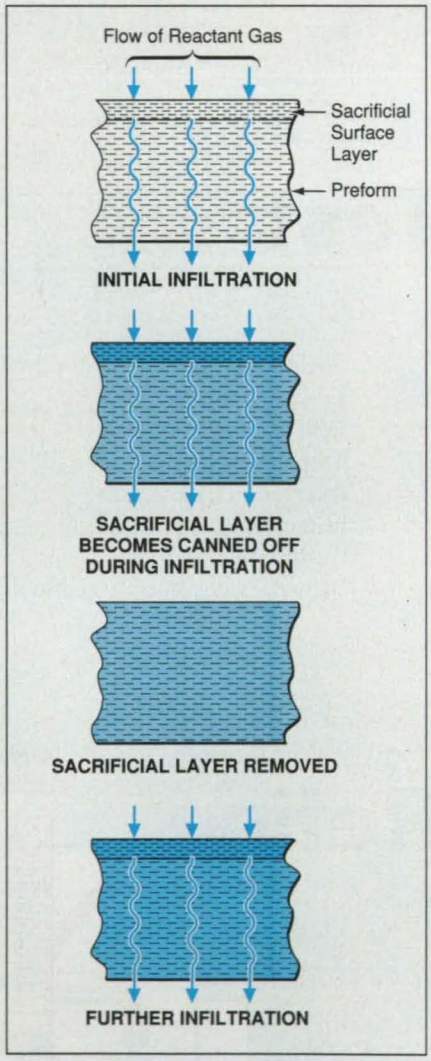
Removable surface layers eliminate the need for time-consuming grinding-off of integral surface layers.

Lewis Research Center, Cleveland, Ohio

A modified chemical-vapor infiltration (CVI) process makes high-quality composites of silicon carbide fibers in silicon carbide matrices. In this process, one adds a sacrificial surface layer of SiC fiber preform that can later be removed easily, by scraping or tapping, when it becomes clogged with infiltrate ("canned off," in CVI terminology).

In comparison with other CVI processes, this process is faster and costs less because unlike the other processes, this one does not involve time-consuming grinding-off of surface layers that have become clogged with infiltrate. This process can be used for making parts that have variable thicknesses and complex, irregular shapes, as well as parts that have constant thicknesses and simple shapes. This process also ensures that the infiltrate consists only of silicon carbide, without the silicon that is sometimes found in SiC/SiC composites made by other processes.

The advantages of this process can be understood better by comparison with one of the other processes; namely, conventional forced-flow isothermal CVI, in which a porous (SiC-fiber) preform is held at con-



The **Modified CVI Process** resembles conventional forced-flow isothermal CVI in some respects, but costs less because it does not include a time-consuming grinding step.

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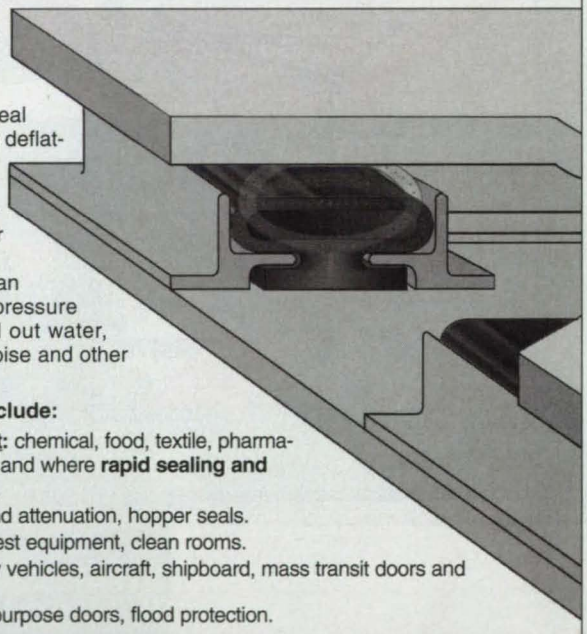

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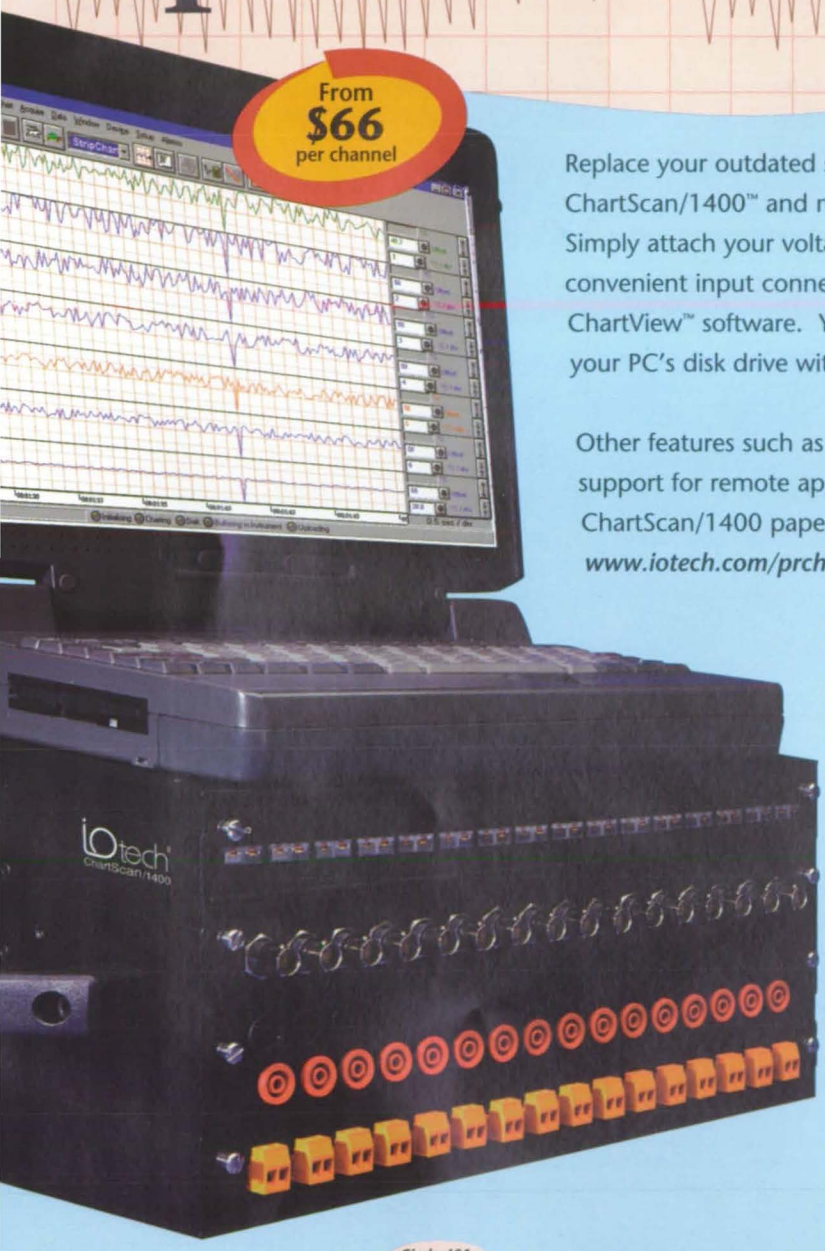

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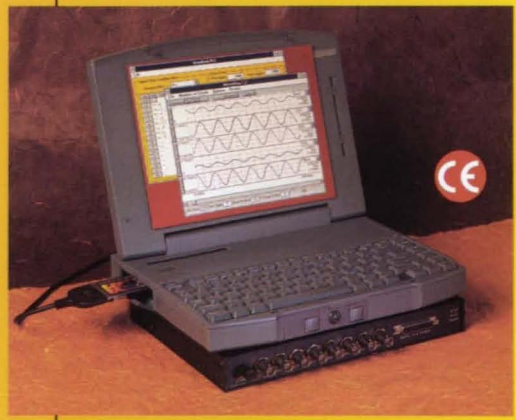

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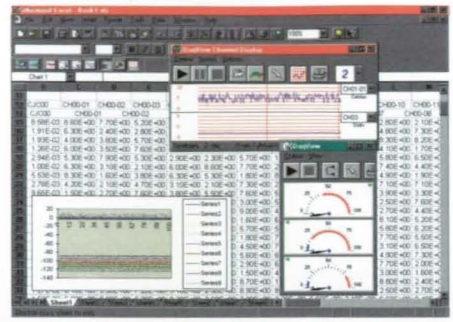

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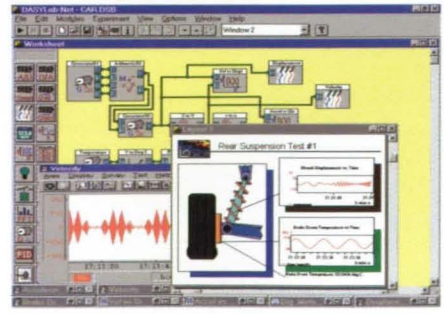

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stant temperature while reactant gases are forced through it. The infiltrating gases react to deposit silicon carbide in the pores. However, pores near the surface tend to become filled before those inside the preform. The canned-off surface pores greatly reduce the rate of infiltration to, and deposition in, the pores deeper in the preform. To promote further infiltration and deposition deep within the preform, the canned-off surface layer must be removed by diamond grinding (this subprocess is called "skinning" in the industry). The ground preform must be then returned to the CVI reactor for further infiltration.

One version of the modified CVI process (see figure) is similar to conventional forced-flow isothermal CVI in some respects. However, unlike in the conventional process, the upstream surface of the preform is first covered with the sacrificial surface layer, which is typically made of either (a) the same material as that of the preform but without a protective fiber coating like that used in the preform or (b) any other high-temperature material that allows diffusion of the reactants and does not become bonded to the preform. The preform is then subjected to CVI. As CVI progresses, the differential pressure of reactant gases across the preform is monitored continuously; when the pressure has risen sufficiently to indicate that the sacrificial layer has become canned off, the preform is removed from the CVI reactor, the sacrificial layer is peeled or tapped off (this takes about two minutes at most), a new sacrificial layer is applied to the surface, and the preform is returned to the reactor for further infiltration.

The sacrificial layer also acts as a diffuser, helping to distribute the reactant gases more evenly. It also acts as a filter, screening out contaminants so that the material deposited in the pores is pure silicon carbide only.

This work was done by M. A. Kmetz, Paul Allard, Dave Wagner, and Chris Kogstrom of United Technologies Pratt & Whitney for **Lewis Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category,* ***or circle no. 113*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

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Unsymmetrical Squaraine Dyes for Nonlinear Optics

Molecular structures are engineered to enhance second-order polarizabilities.

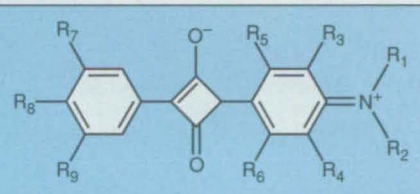
NASA's Jet Propulsion Laboratory, Pasadena, California

Dyes based on unsymmetrical squaraine molecules (see Figure 1) have been invented for use in a variety of optical devices that exploit nonlinear optical properties to change the frequency and/or polarization of light in useful ways. Examples of such devices include second-harmonic generators, spatial light modulators, parametric oscillators, and some interferometers.

The unsymmetrical squaraine molecular structures are engineered to obtain large values of first electronic hyperpolarizability (β); that is, the second-order polarizability that gives rise to the desired nonlinear optical response.

The molecular-engineering strategy is derived from some observations concerning two limiting charge-transfer resonance forms that occur in the molecules of interest. Each molecule can be characterized, in part, by a linear combination of these two forms. If one form completely dominates, the molecule is designated as being polyenelike; if the two forms contribute equally, the molecule is designated as being cyaninelike. It has been discovered that (a) it is necessary to obtain an optimal linear combination of the two forms in order to maximize β, and that (b) the value of β can be correlated with the bond-length alternation (BLA), which is the difference between the lengths of adjacent carbon-carbon bonds. As one proceeds from a polyenelike limit (BLA > 0.12 Å) to a cyaninelike limit (BLA = 0 Å), β reaches a peak at BLA ≈ 0.04 Å.

Past efforts to reach this peak from the polyene limit by adding electron donors or acceptors to decrease the magnitude of BLA have usually resulted in BLA > 0.10 Å — far from the value needed to maximize β. The development of the present unsymmetrical squaraine dyes followed a different approach — starting from the cyanine limit of BLA = 0. Squaraine dyes are analogous to cyanine dyes in that like cyanine dyes, they are characterized by two degenerate resonance forms and sharp and intense visible or near-infrared absorption spectral



Notes:

1. R_1 is alkyl, $(CH_2)_nOH$ where n = 1 to 8, $(CH_2)_nSH$ where n = 1 to 8, phenylmethyl, or 4-halophenylmethyl. Alternatively, $R_1 + R_3 = (CH_2)_3$.
2. R_2 is alkyl, $(CH_2)_nOH$ where n = 1 to 8, $(CH_2)_nSH$ where n = 1 to 8, phenylmethyl, or 4-halophenylmethyl. Alternatively, $R_2 + R_4 = (CH_2)_3$.
3. $R_1 + R_2$ is derived from a cyclic amine of the form $N(CH_2)_n$, where n = 3 to 10.
4. R_5 is H, F, OH, SH, CH_3, C_2H_5, OCH_3, or SCH_3.
5. R_6 is H, F, OH, SH, CH_3, C_2H_5, OCH_3, or SCH_3.
6. R_7 is H. alkyloxy or aryloxy.
7. R_8 is H, alkyloxy, or aryloxy.
8. R_9 is alkyloxy, or aryloxy.

Figure 1. This **General Structural Formula** is only one of nine such formulas that describe the numerous unsymmetrical squaraine dyes of the invention. Note the wide variety of compounds represented by variations in the groups R_1 through R_9.

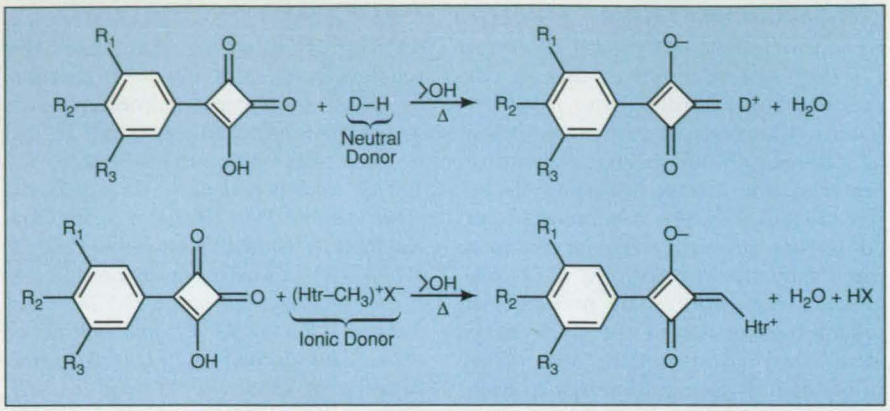


Figure 2. These **Dyes Are Synthesized** by condensing monosubstituted squaric acid precursors with neutral or ionic donors.

bands. However, unlike ionic cyanines, squaraines are neutral molecules that are suitable for measurement of electric-field-induced second-harmonic generation.

The unsymmetrical squaraine dyes of this invention are synthesized by condensing monosubstituted squaric acids with neutral or ionic donors. For example, in the synthesis illustrated in the upper part of Figure 2, the monosubstituted squaric acid precursors could be 1-(4-isopentyloxyphenyl)-2-hydroxycyclobutene-2,4-dione, and the neutral donor (D-H) could be 4-N,N-dibutylamino-3′,5′-dihydroxystilbene. For another example, in the synthesis illustrated in the lower part of Figure 2, the monosubstituted squaric acid precursor could be 1-(4-methoxyphenyl)-2-hydroxycyclobutene-2,4-dione and the ionic donor (Htr-CH_3)+X– could be N-butyllepidinum iodide.

Depending on specific applications, these dyes can be used alone (e.g., in crystalline and/or thin-film form) or can be incorporated into thin films, crystals, liquids, and/or gases in mixtures with other materials that are conventionally used in nonlinear optical devices. A particularly convenient and effective way of using a dye of this invention is to disperse the polar dye molecules in a polymeric binder. The polymer/dye mixture can be heated to a temperature at which the polymer becomes sufficiently soft so that upon application of an electric field, the polar molecules line up along the direction of the field. When the mixture cools, the polar molecules are locked into their field-aligned orientation, and so the electric field can be removed without loss of orientation.

This work was done by Seth R. Marder, Chin-Ti Chen, and Lap-Tak Cheng of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category,* ***or circle no. 142*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

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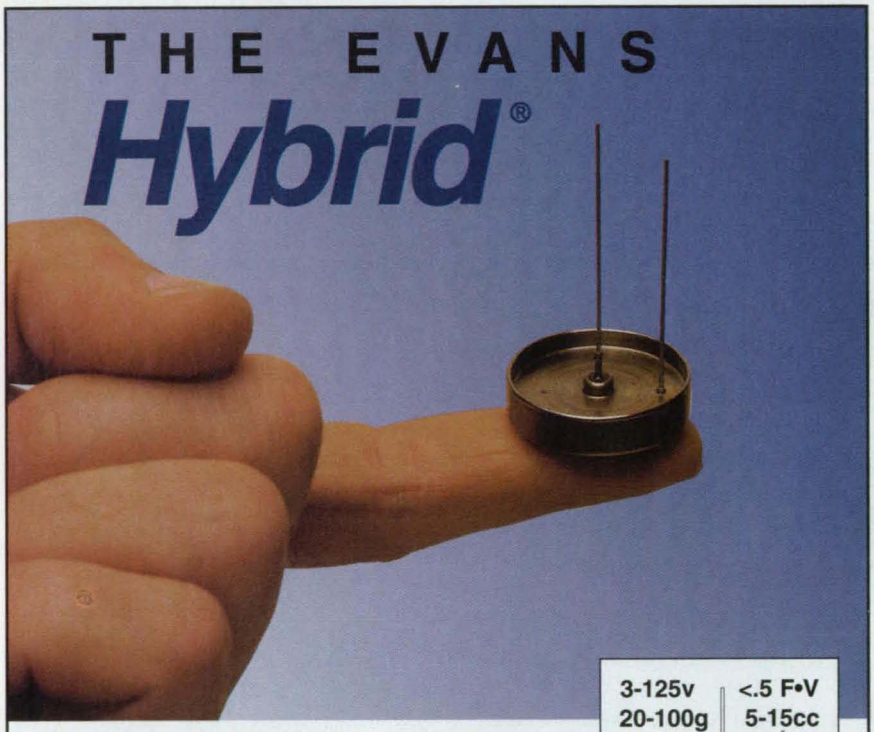

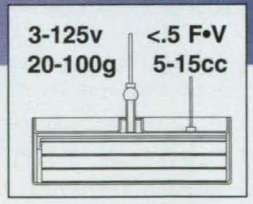

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For More Information Circle No. 507

Computer Software

The SPICE System

The Navigation and Ancillary Information Facility (NAIF) at JPL has built a multimission, multidiscipline information system named SPICE, which is of use to scientists and engineers involved with mission evaluation, mission operations, observation planning, and science data analysis. SPICE has two principal components — a set of data file specifications and a collection of software used to write SPICE files and to read and utilize the data within SPICE files. The SPICE files, called "kernels," contain a variety of space science geometry, including ephemerides and size, shape, and orientation for planets, satellites, comets, and asteroids; spacecraft trajectory; spacecraft orientation; and instrument viewing geometry. Also included in SPICE files is nongeometric information, such as sequence of events and electronic notebook. The software component of SPICE is the NAIF Toolkit. The principal component of this Toolkit is a large library of FORTRAN subroutines known as SPICELIB. Included in SPICELIB are subroutines used in both writing and reading SPICE kernel files, and higher-level routines used to process SPICE kernel data to compute a wide assortment of observation geometry, such as observer-target direction and range, sub latitude and longitude, lighting angles, and the like. Users integrate selected NAIF Toolkit routines into their own application programs to help accomplish whatever objectives are at hand. The kernel file structures and Toolkit software are designed with portability as a key attribute: the SPICE system will work on any computer that supports ANSI FORTRAN 77, and C language interfaces to the most used subroutines are being added. Flexibility is also a key attribute: the system architecture is easily extended to handle new requirements. A customer may choose to use a subset of the SPICE capabilities. SPICE defines the data standards for ancillary data to be archived within NASA's Planetary Data System. SPICE is used on most NASA planetary missions. It has been used to support a number of astrophysics and space physics applications, and has been successfully demonstrated with Earth-observing spacecraft. SPICE is also used by terrestrial observatories.

This program was written by Charles Acton, Nathaniel Bachman, Kevin Gehringer, William Taber, and Boris Semenov of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Computer Software category,* ***or circle no. 164*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

NPO-19984

Program for Analyzing Flutter of Propfan Blades

Stimulated by the interest in improvement of aircraft fuel efficiency, Lewis Research Center initiated an effort to develop refined analytical methods and associated computer codes for predicting flutter of propfans. The ASTROP2 computer program performs aeroelastic-stability analysis of rotating propfan blades. It uses strip theory to integrate aerodynamic forces calculated by use of a two-dimensional model of aerodynamics with a three-dimensional model of the structure.

The flutter analysis is performed by two separate subprograms. The first subprogram calculates the structural dynamics at the strips required for the analysis of aeroelasticity. The second subprogram uses the structural data from the first subprogram and calculates the aeroelastic stability. Each subprogram can be used and modified independently.

ASTROP2 is written in FORTRAN 77 and has been successfully compiled and run on a SUN 4 SLC workstation running SunOS 4.1.3_U1, an SGI IRIS INDIGO workstation running IRIX 6.2, and a SUN 4 IPC workstation running SunOS 5.4/Solaris 2.4. The program also functioned properly on a CRAY/Y-MP computer running UNICOS 8.0.4.1 with the CFT77 6.0.5.0 compiler. The standard distribution medium for ASTROP2 is a 4-mm digital audio tape in UNIX tar format. Alternate distribution media and formats are available on request. ASTROP2 was released in 1996.

This program was written by J. M. Lucero of **Lewis Research Center**, *T. S. Reddy of the University of Toledo, and G. V. Narayanan of Sverdrup, Inc. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Computer Software category,* ***or circle no. 146*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

LEW-16407

Computer Program for Emulating MIL-STD-1750a Computer

CPU_1750a is a software program that implements the MIL-STD-1750a Military Standard Sixteen-bit Computer Instruction Set Architecture. It emulates a MIL-STD-1750a compliant computer hardware system.

CPU_1750a provides a unified mechanism for integration with software that emulates peripherial hardware. It is used to implement a software emulation of a complete digital avionics system such that MIL-STD-1750a software may be developed and

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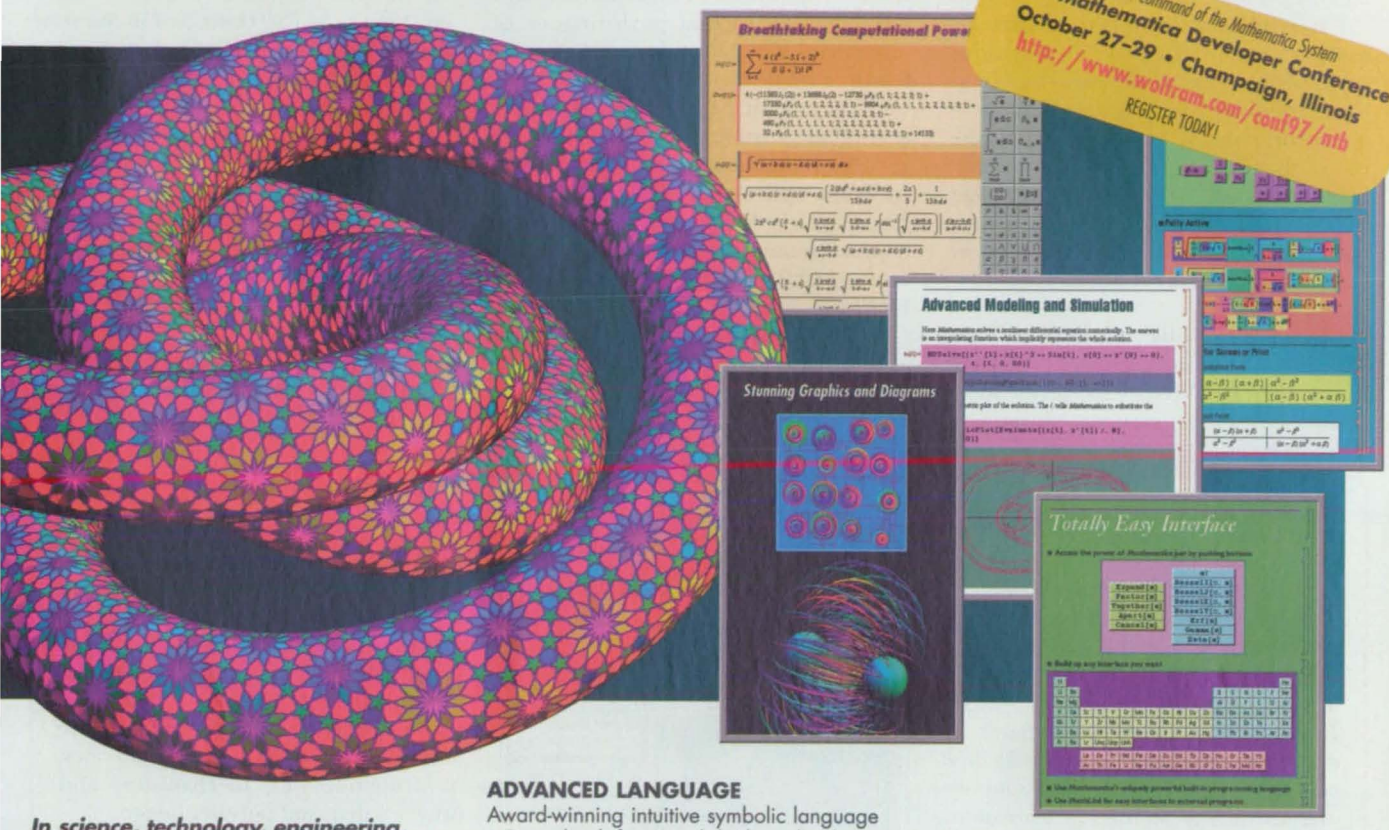

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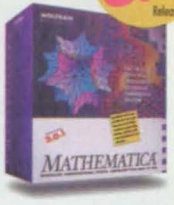

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tested prior to the availability of hardware. The extensive visibility provided by CPU_1750a allows development and debugging to proceed more rapidly than is possible on many hardware-based development systems.

Powerful user interfaces can be quickly created. CPU_1750a provides read/write access to internal state (registers, memory, and page registers, and emulator control variables and functions) that is designed to be comparable with Tool Command Language (Tcl). Breakpoints and instruction trace are controlled via Tcl, and may in turn activate Tcl procedures upon activation.

CPU_1750a fully implements the MIL-STD-1750a instruction set. It passes all SEAFAC VSW V2.1 verification tests. CPU_1750a can be configured with multiple personalities, which can be selected during runtime. Three personalities are currently available: MIL-STD-1750a, IBM GVSC, and IBM GVSC with breakpoints and instruction trace capability. Personalities are implemented so that performance of one personality is not dependent upon features implemented in another personality so that performance is always as high as possible.

CPU_1750a implements all mandatory and optional MIL-STD-1750a features, including: interval timers, expanded memory, memory block protect, startup ROM, and access lock/key.

CPU_1750a is written in C++. It executes over 400,000 instructions per second on a Sun SPARC 10/51.

This program was written by William K. Reinholtz and Mohammad Shahabuddin of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Computer Software category,* ***or circle no. 126*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

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Refer to NPO-19734, volume and number of this NASA Tech Briefs *issue, and the page number.*

NASA's Software of the Year

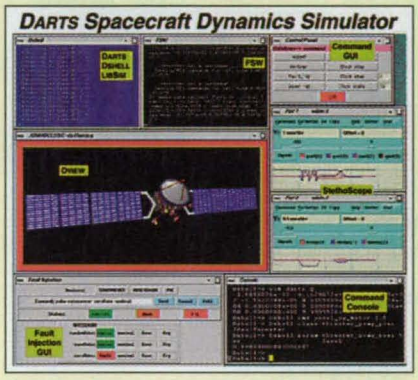
NASA's 1997 Software of the Year Awards will be presented on September 23 at a special Awards Reception during Technology 2007 to be held in Boston from September 22-24. Chosen by NASA's Inventions and Contributions Board, the awards are given to individuals who develop software that enhances NASA's missions and assists U.S. industry in maintaining world-class technology status.

1997 Winner:

Dynamics Algorithms for Real-Time Simulations (DARTS), developed by NASA's Jet Propulsion Laboratory, Pasadena, CA (Drs. Abhinandan Jain, Guillermo Rodriguez, and Guy K. Man)

The 1997 Software of the Year was used by JPL to keep the Pathfinder spacecraft on course as it cruised toward Mars. DARTS software has saved over $10 million to date on NASA missions including Pathfinder, Galileo, and Cassini. It is a high-fidelity, flexible multibody dynamics simulator used for real-time hardware-in-the-loop design, integration, and testing of spacecraft flight software. DARTS allows the use of high-fidelity spacecraft dynamics models without sacrificing simulation speed, enabling more reliable flight-software design and testing, reduced development costs, and increased mission safety.

During Pathfinder's journey to Mars, the slightest variation in trajectory would have sent the spacecraft far afield of its target. The flight plan included five midcourse corrections during which the spacecraft's thrusters would fire to refine its trajectory. NASA controllers ran commands through DARTS before sending signals to Pathfinder. This enabled them to verify that a command would have the desired result. During Pathfinder's seven-month flight, mission controllers made four midcourse corrections using DARTS. There was no need for a fifth: Pathfinder was still dead on target.



DARTS software helped keep Mars Pathfinder on course; it also has potential in the research and development of new drugs, catalysts, and polymers.

DARTS is based on a new form of mathematics called Spatial Operator Algebra (SOA), which also was invented by Drs. Jain, Rodriguez, and Man. SOA is a mathematical approach for modeling the dynamic behavior of complex, articulated collections of bodies interacting with each other in free-space or in contact with the environment.

DARTS was used to guide the Galileo spacecraft through its course around Jupiter's four largest moons, and it will be an important part of the Cassini mission to Saturn. SOA-based software also may help scientists uncover the structure and function of proteins and enzymes; of protein-folding mechanisms; and drug, catalyst, and polymer designs.

1997 Runners Up:

(in alphabetical order):

- ***Micromechanics Analysis Code with Generalized Method of Cells (MAC/GMC)***, developed by NASA's Lewis Research Center, Cleveland, OH (headed by Dr. Steven M. Arnold) A comprehensive program for predicting a material's response to thermal and mechanical loads.

- ***STructural Analysis RoutineS (STARS)***, developed by NASA's Dryden Flight Research Center, Edwards, CA (headed by Dr. Kajal K. Gupta) An analysis package of integrated finite element software developed for the solution of linear and nonlinear engineering problems.

- ***Thickness-Independent Ultrasonic Imaging Software***, developed by NASA's Lewis Research Center, Cleveland, OH (headed by Dr. Don J. Roth) The software enhances materials characterization by ultrasonic imaging, eliminating the effects of sample-thickness variations.

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Focus-Ring Mechanism Translates Lenses Without Rotation

The parts of the mechanism need not be highly precise.

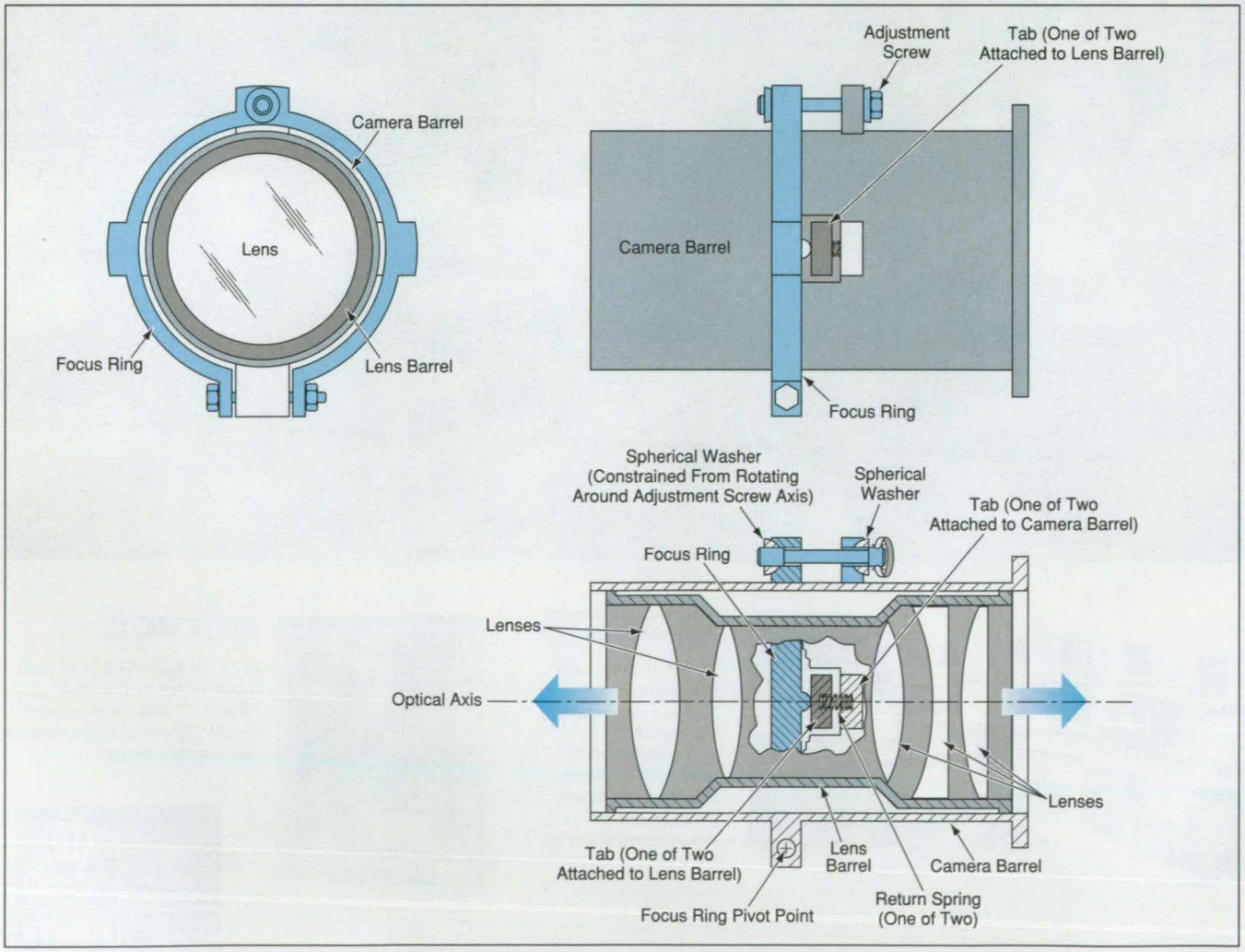
NASA's Jet Propulsion Laboratory, Pasadena, California

The figure illustrates a camera lens barrel and a mechanism for translating the lens barrel along its optical axis. Unlike some other focusing mechanisms, this one does not rotate the lens barrel about the optical axis — an essential feature if the lenses and/or other optics in the barrel are asymmetric and are required to be kept in a specified alignment with respect to a line in the focal plane.

The lens barrel slides axially within a stationary camera barrel. The mechanism includes a focus ring that is approximately concentric with the barrels. The focus ring pivots about a fixed point under the camera barrel, and the tilt of the ring can be varied by use of an adjustment screw atop the camera barrel. As the tilt of the ring changes, it pushes axially on (or allows itself to be pushed axially by) tabs on the lens barrel. These tabs are spring-loaded against similar but fixed tabs on the camera barrel. As the tabs on the lens barrel push against (or are pushed by) the spring load, the lens barrel translates along the axis.

The adjustment screw could be any of a variety of suitable screws with standard fine pitches, e.g., 32 threads per inch [pitch of 0.3125 in. (about 0.79 mm)]. Because the point of contact between the ring and the lens barrel is halfway along the lever arm, the axial translation of the lens is half that of the adjustment screw. Thus, continuing the above example, one full turn of the screw translates the lens assembly about 0.016 in. (0.4 mm), while a partial turn of 10° translates the ring only about 0.00043 in. (0.011 mm).

The only motion-producing surfaces that need be machined to high precision are the outer-diameter surface of the lens barrel and the inner-diameter surface of the camera barrel; these surfaces are required to mate with each other in a smooth sliding fit with mini-



Rotation of the Adjustment Screw pivots the ring slightly, causing the ring to push on the tabs and thereby translate the lens barrel along the optical axis.

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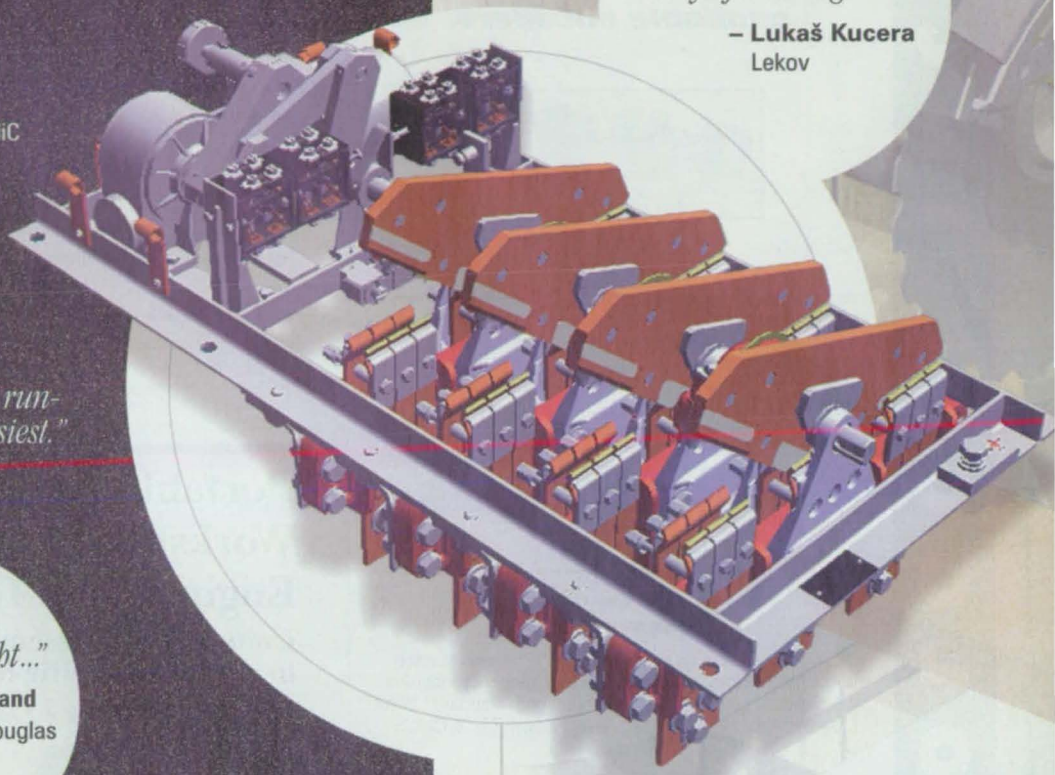

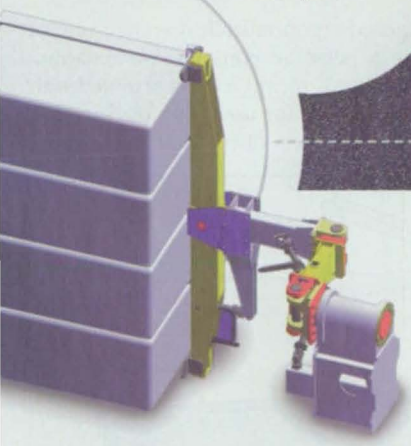

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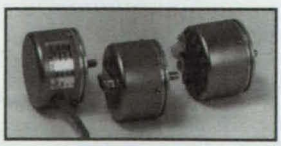

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mal radial play. The parts of the focusing mechanism can be fabricated without high precision. The adjustment screw and the spherical bearings on which the ends of the adjustment screw turns can be fabricated easily and inexpensively.

The mechanism can be upgraded in several ways. The adjustment screw could be modified to accept a motor drive so that the lens system could be focused under remote control. The adjustment screw could be made as a differential screw by machining it with dual threads, each having a slightly different pitch; this would greatly increase the resolution of the focus adjustment. Radial play could be eliminated by mounting the lens barrel on flexures configured to allow movement along the optical axis; in that case, it would no longer be necessary to enclose the lens barrel in a camera barrel.

This work was done by Richard E. Fleischner of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category, or* ***circle no. 156*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*
NPO-19711

Portable Computer Workstations for Engineering Teams

Units could be assembled in modular fashion to perform specific team engineering tasks.

NASA's Jet Propulsion Laboratory, Pasadena, California

Figure 1 illustrates a proposed ergonomically designed unit of furniture that would house a personal computer workstation. The unit could be used alone but is meant to be assembled with other such units in modular fashion for use by an engineering design team. The unique configuration of the unit is chosen to

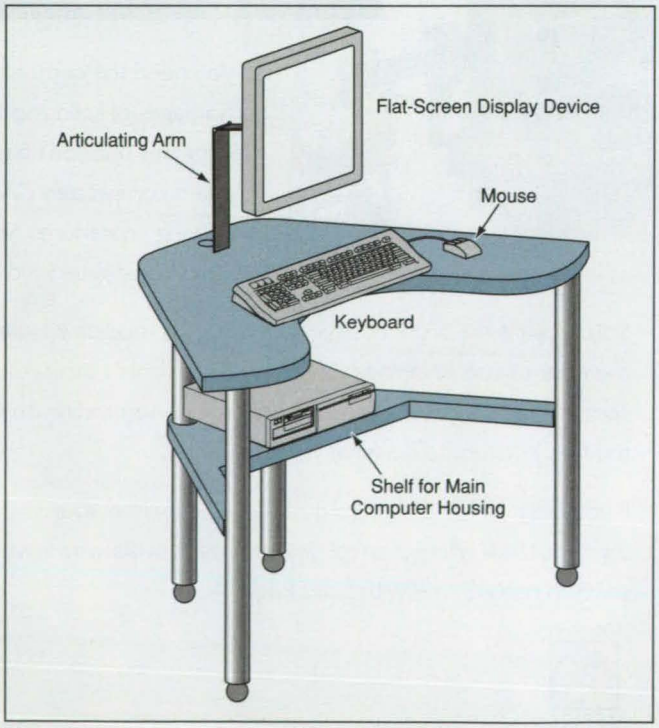

Figure 1. The **Ergonomic Design of This Unit** would provide for efficient utilization of space and adjustability for the user's comfort.

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facilitate face-to-face verbal and visual communication and thereby promote collaboration among engineers on the team who specialize in different disciplines.

The main computer housing would be placed on the shelf below the table to maximize the work space available to the user on the table. The shelf would be set back to provide room for the seated user. The height of the table could be adjusted to suit the user, or to enable storage of the unit under a conference table or other piece of furniture.

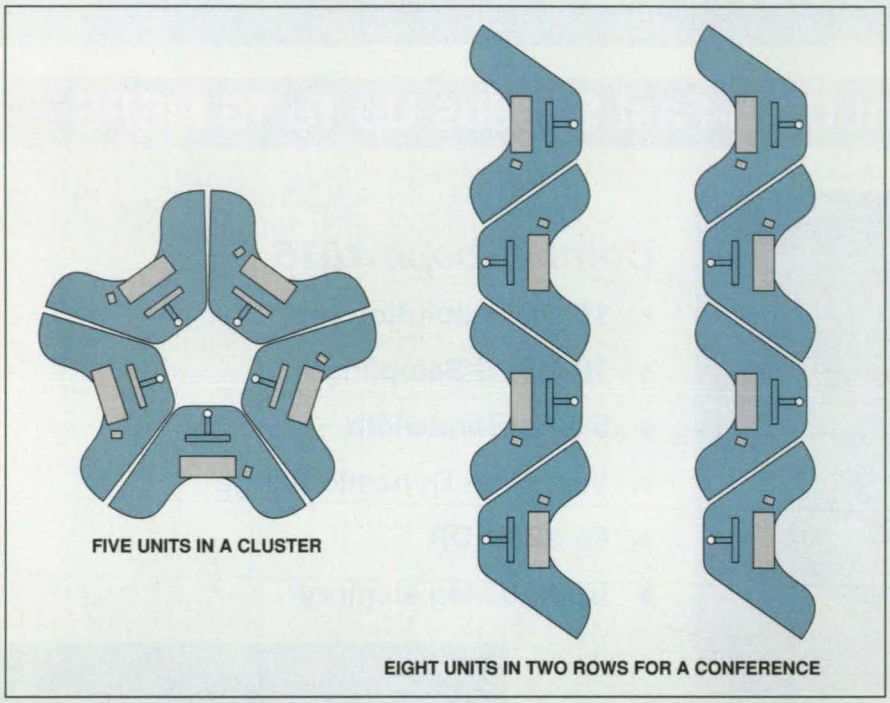

Figure 2. **These Are Only Two** of many possible ways in which multiple units could be arranged to promote collaboration among multiple users.

The computer video output would be presented on a large, high-resolution, flat-screen display device, which would be mounted on an articulating arm that the user could adjust to position and orient the screen for comfort in viewing. The articulating arm could also be used to fold the screen out of the way for storage.

The peculiar nonrectangular shape of the table is chosen to please the eye and to promote creativity. Because of its bilateral symmetry, the table would be suitable for either a right- or a left-handed user. The unit would be light in weight and mounted on wheels for portability. Multiple units could readily be wheeled together in any of a large variety of cluster or line arrangements (see Figure 2) according to the number of collaborators and the preferred mode of interaction.

This work was done by Danette G. Klein and James Duke of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category, or* ***circle no. 129*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*
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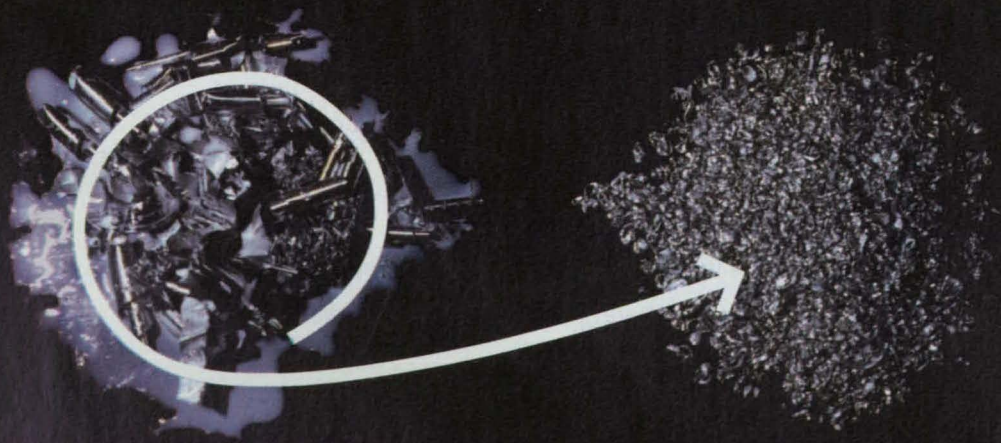

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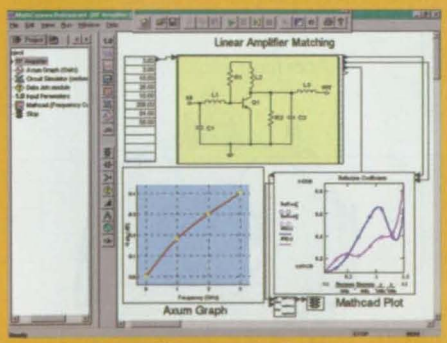

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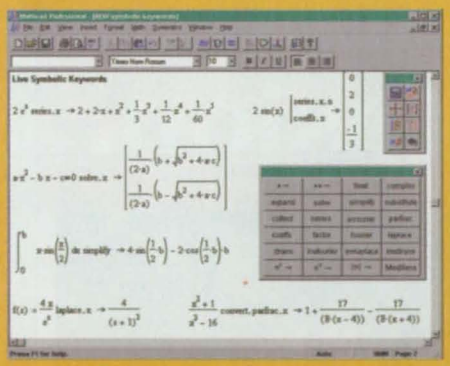

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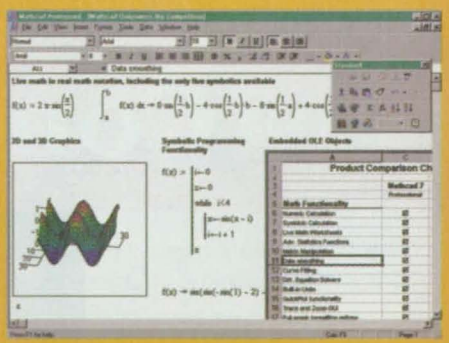

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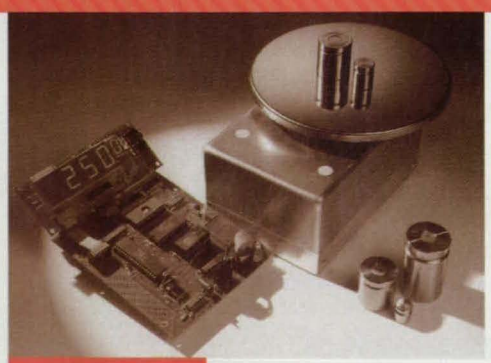

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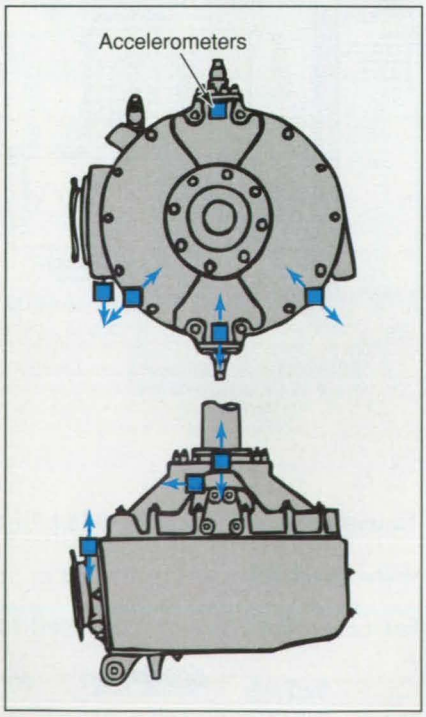
Model-Based Placement of Gearbox-Monitoring Accelerometers

Locations are ranked with respect to utility for measuring vibrations to diagnose faults.

Lewis Research Center, Cleveland, Ohio

A model-based methodology has been devised as a systematic means for selecting locations of accelerometers on a helicopter gearbox to measure vibrations indicative of cracked or pitted gear teeth, damaged bearings, and other gearbox faults. In the envisioned application, the outputs of the accelerometers would be fed to an onboard computer and processed to diagnose faults during flight. However, it is not practical to install and process the readings of a large number of accelerometers, each positioned on or near a gearbox component vulnerable to failure. The problem then becomes one of selecting locations for a limited number of accelerometers in such a way as to



A **Helicopter Gearbox** was instrumented with accelerometers at eight locations for experiments on monitoring vibrations to diagnose faults.

obtain the required diagnostic capability to some quantifiable degree. The methodology offers a solution that involves quantification of the significance of each accelerometer and its location in diagnosis.

Ideally, the significance of each accelerometer and its location could be determined empirically by comparing the results of diagnoses performed with and without the accelerometer. However, to be able to do this, one would need a comprehensive set of measurement data associated with all possible faults; in general, such a set of data is not available. The methodology provides a partial substitute for such an empirical assessment, on the basis of (a) relationships between component faults and accelerometer readings as expressed by an influence mathematical model obtained from (b) a lumped-masses-and-springs simplified mathematical model of the vibrational properties of the gearbox.

The influence model is used to compute the following three indices that represent the effectiveness of accelerometers for monitoring various gearbox components:

- The diagnosability index for each component is defined as a sum of coefficients of influence of that component on all the accelerometers, and is taken to be an indication of the ability to diagnose a fault in that component.
- The coverage index of an accelerometer is defined as a sum of coefficients of influence of all gearbox components on that accelerometer, and is taken as a measure of the "reach" or "coverage" of the accelerometer; that is, of the number of gearbox components that the accelerometer can monitor.
- The redundancy index of an accelerometer is a measure of the overlap of the sensory domain of that accelerometer with the sensory domains of other accelerometers; an accelerometer is deemed to be redundant if the components it covers are already covered, with greater coefficients of influence, by other accelerometers.

Accelerometers alone or in groups can be ranked according to the effects of the deletion of the specified accelerometers upon these indices. Those accelerometers, the deletion of which would result in the greatest losses in the values of these indices, are ranked highest to indicate their significance in diagnosis.

This model-based methodology was tested in experiments on an OH-58A main rotor gearbox. In the experiments, piezoelectric accelerometers were installed at eight locations on the gearbox (see figure) and used to measure vibrations in five tests that lasted for various numbers of days. During the tests, nine pitting failures and two cracking failures occurred. The outputs of the accelerometers were digitized and processed by diagnostic algorithms. The model-based methodology was applied and used to rank the individual accelerometers. These rankings were found to agree well with rankings obtained empirically.

This work was done by Vinay B. Jammu, Keming Wang, and Kourosh Danai of The University of Massachusetts and David G. Lewicki of the Propulsion Directorate of the U.S. Army Research Laboratory for **Lewis Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category, or* ***circle no. 123*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

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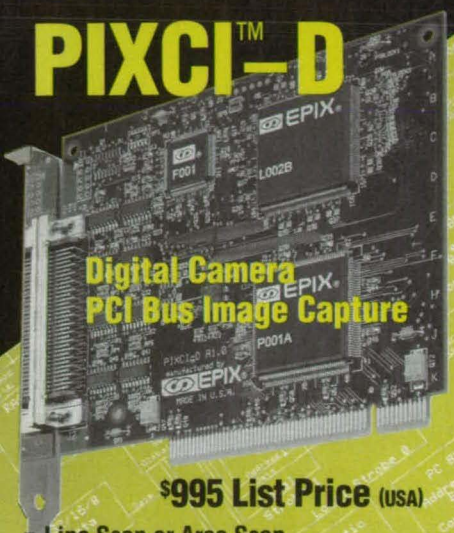

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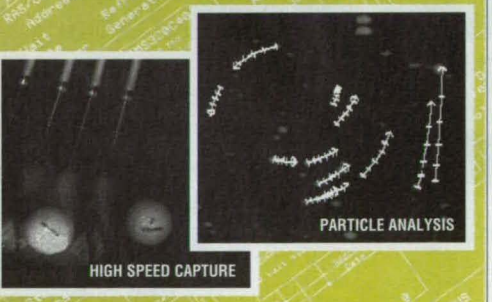

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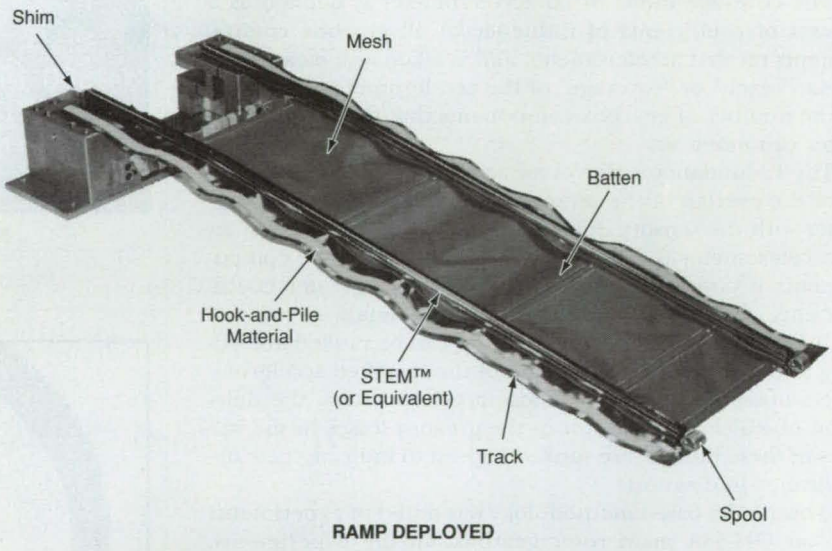
Rolled-Up Ramp Deploys Itself on Command

The ramp unfurls itself when pyrotechnic cutters are activated to release bindings.

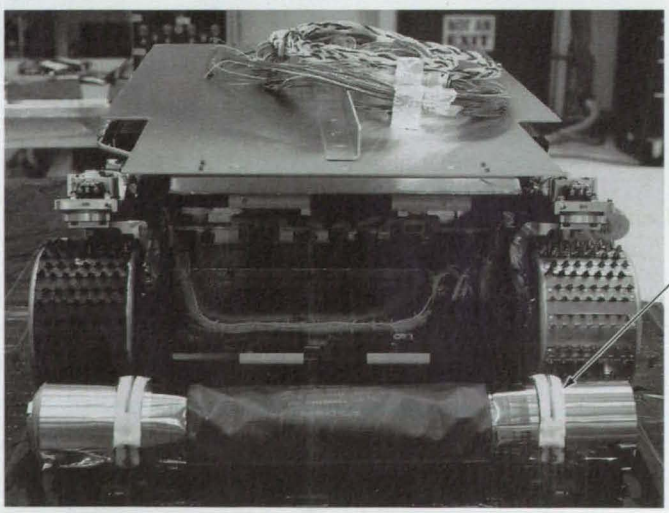
NASA's Jet Propulsion Laboratory, Pasadena, California

The figure illustrates various aspects of a springy ramp that can be rolled tightly into a cylinder, which is then wrapped circumferentially with tie-down cables. On subsequent command, pyrotechnic devices can be activated to cut the tie-down cables, causing the ramp to deploy itself by unrolling under its own spring force. The ramp was designed to facilitate the egress of a small rover vehicle from the Mars *Pathfinder* spacecraft; modified versions of the ramp might be useful on Earth as compactly stowed, lightweight, deployable emergency-exit ramps in buildings, land vehicles, and aircraft.

Lying lengthwise along the track are two stainless-steel tubular spring (STEM™, or equivalent) elements that can be pushed flat, against their springiness, for stowage. These elements provide the required strength, stiffness, and deployment force. Five crosswise aluminum alloy battens are attached to the STEM™ (or equivalent) elements. Thin stainless-steel tracks are located on the outboard side of



RAMP DEPLOYED



STOWED RAMP ASSEMBLY

The **Ramp Can Be Rolled** into a cylinder for compact stowage until needed. On command, it unrolls itself under its own spring force.

each spring element; in the original spacecraft application, these are the surfaces along which the vehicle wheels are intended to roll. The tracks are attached to the STEM™ (or equivalent) and battens by screws and rivets, respectively. The tracks play a large role in reacting all inplane shear loads.

A lightweight aromatic polyamid/epoxy open-weave mesh covers the midspan of the ramp over most of its length. The mesh is attached to, and sandwiched between, the STEM™ (or equivalent) elements and tracks, and is pocketed for restraint at each batten. A cylindrical spool is attached to the outboard tip of each track and centered on the axis of the corresponding STEM™ (or equivalent) element. The spools assist during initiation of roll-up for stowage.

The inboard end of each STEM™ (or equivalent) element is fastened to a shim, which in turn, is attached to a mounting surface. Continuous strips of stainless-steel/nylon hybrid hook-and-pile material are attached to the outer sides of the top and bottom surfaces of the tracks. These strips resist peeling with just enough force to reduce the speed of unrolling and to damp spurious unrolling movements, ensuring coordinated deployment movement like that of a carpet unrolling from a fixed end.

When stowed, the ramp is rolled up into a cylinder 7.62 cm in diameter and 42 cm long. Once the pyrotechnic devices are actuated, it takes the ramp about 1 second to unroll to its full length of 136 cm.

This work was done by Lee Sword, Howard Eisen, and Curtis Tucker of Caltech and Brian Spence, Keith Edwards, Jack Sanders, and Geoff Marks of Astro Aerospace for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category, or* ***circle no. 111*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

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Identifying Loose Joints in an Adaptive Truss Structure

Gaps are measured in a sequence of static force-vs.-displacement measurements.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method of identification of loose joints in an adaptive truss structure is based on identification of nonlinear force-vs.-displacement behaviors in the structural members connected via the loose joints (see Figure 1). "Adaptive truss structure" as used here denotes a truss structure, at least some of the members of which are active (see Figure 2). An active member is one that contains an actuator that can apply a controllable force to the ends of the member and/or cause a controllable change in the length of the member.

Truss structures are made adaptive to provide active control for suppression of vibrations and/or to maintain precise geometric relationships among optical components mounted on the structures. Accurate knowledge of the stiffness characteristics of a structure is necessary for precise control. It is important to identify loose joints because looseness gives rise to large changes in stiffness. When either or both joint(s) at the end of a member is (are) loose and the state of the structure is such that the ends of the member lie within the looseness gap, then the member does not interact with the rest of the structure and thus does not contribute to the stiffness of the structure. The effect on the structure is equivalent to that of removing the member.

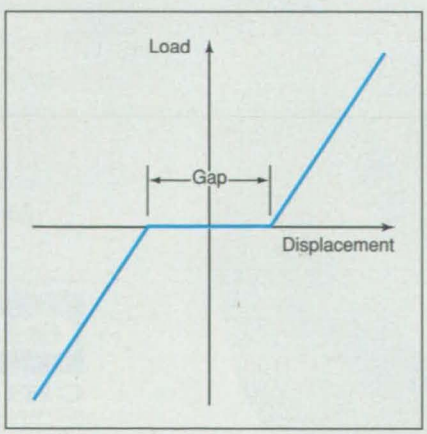
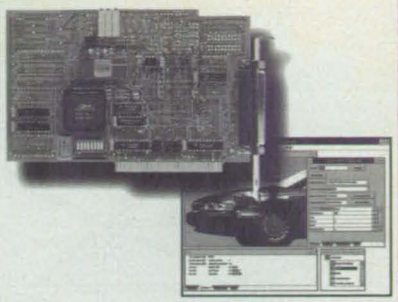


Figure 1. The **Load-vs.-Displacement Curve** for a member with a loose joint is nonlinear in that it exhibits zero stiffness within the looseness gap and nonzero stiffness on both sides of the gap.



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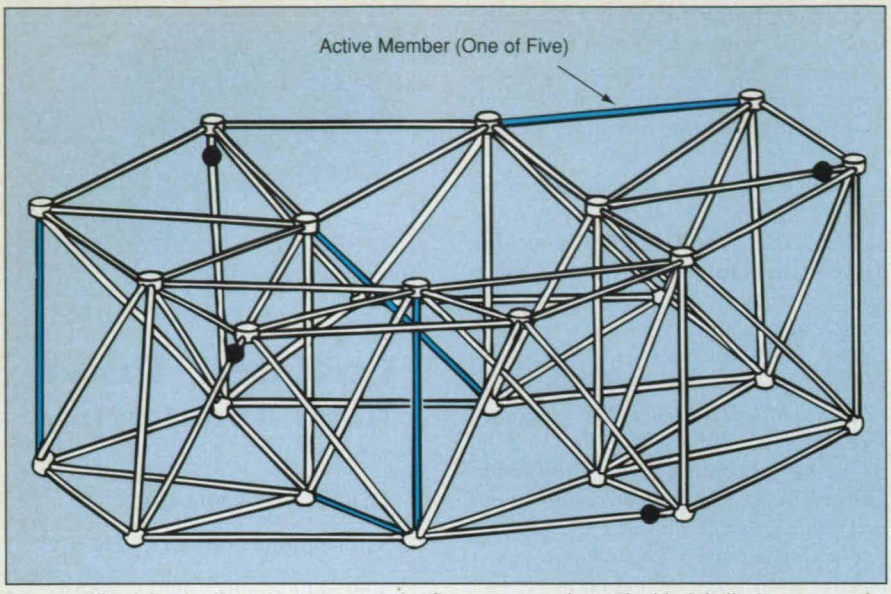

Figure 2. This **Adaptive Truss Structure** contains five active members. The black balls shown near the ends of four of the passive members indicate that the joints at those ends of those members are loose.

The method of identification of loose joints involves instrumenting the structure with displacement sensors and using some or all of the actuators that are already in the structure. First, some combination of actuators is used to stress the structure enough to close all gaps. With all gaps closed, the structure can be expected to exhibit linear load-vs.-displacement characteristics.

Next, the applied loads are decreased by small amounts while the corresponding decrements in the displacements are measured. If there is a loose joint, then at some point in the unloading process, the gap in it will open. A nonlinearity in the plot of load-vs.-displacement data obtained in this unloading process indicates that a gap has opened somewhere in the structure. When the unloading process is complete, the accumulated number of such nonlinearities indicates the total number of gaps that have opened and thus the number of loose joints.

Once the number of loose joints has been established, their locations and the sizes of the gaps in them are determined, one by one, in a recursive sequence of measurements and calculations. In this sequence, known displacements are applied via the active members and the displacements of the ends of the other members are measured and compared with displacements computed according to linear (no-gap) force-vs.-displacement relations to identify specific gap-opening nonlinearities in joints in which they occur.

This work was done by Robin J. Bruno of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category, or* ***circle no. 120*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

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Heat Pump for Quick Warming of Automobile Passenger Space

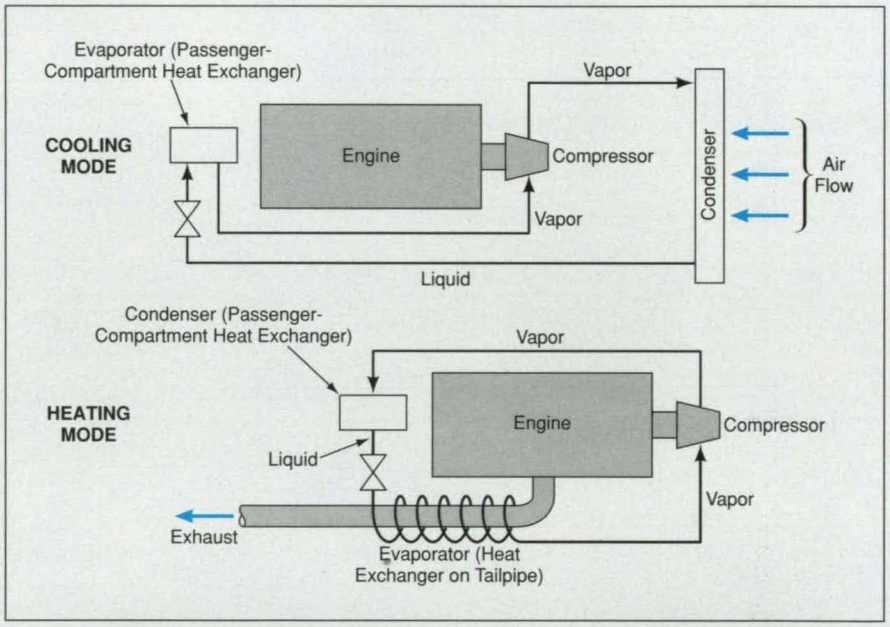
The air-conditioner would be operated in reverse, drawing on exhaust heat.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed system for quick heating of the passenger compartment in a cold automobile would exploit the vapor-compression cycle of an automotive air-conditioner. The system would likely cost and weigh less than do quick-heating systems based on storage and release of heat in phase-change materials. Unlike an electric heater, this system would not impose an excessive additional drain on the automobile battery.

The proposed system would consist mostly of an ordinary automotive air-conditioning system, with some additional switches, valves, and plumbing to enable operation in either the quick-heating mode or the traditional cooling mode. In the quick-heating mode, the vapor-compression cycle would be run in reverse: whereas the passenger-space heat exchanger serves as an evaporator that takes heat from the passenger space in the cooling mode, it would serve as a condenser that would deliver heat to the passenger space in the quick-heating mode (see figure).

The evaporator for the quick-heating mode would be an additional heat exchanger in direct or indirect contact with the exhaust pipe; this would make it possible to provide much more heat than could readily be extracted from cold ambient air. Even in the coldest weather, a typical cold idling engine produces ample low-grade exhaust condensation heat in the approximate temperature range of 70 to 110 °F (21 to 43 °C). The refrigerant fluid passing through the evaporator would absorb some of this heat, and compression would raise the temperature of the fluid passing through the condenser to about 150 °F (66 °C). This fluid temperature is typical for an automotive heater.



The **Vapor-Compression Cycle** of the air-conditioner would be exploited for traditional cooling or for quick heating, depending on valve and switch settings that would delineate flow paths.

One potential disadvantage of this system is that the chlorofluorocarbon refrigerant fluid of a typical automotive air-conditioner could decompose when exposed to very high exhaust temperatures. It is possible, however, to overcome this disadvantage by use of a thermal switch, such as a manifold, to divert the flow of exhaust from the evaporator once the engine has warmed up. Alternatively, a more stable refrigerant could be used, such as CO_2, which has recently been demonstrated on automobile air-conditioning systems.

This work was done by Jack A. Jones of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category,* ***or circle no. 165*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*
NPO-19868

Designing Electrically Powered Actuators for Aircraft

Flight controls will be operated by relatively lightweight power-by-wire systems.

Dryden Flight Research Center, Edwards, California

Under the Electrically Powered Actuation Design (EPAD) validation program and as part of a joint Air Force/Navy/NASA effort, Dryden Flight Research Center has begun testing an electrohydrostatic actuator (EHA) in its F/A-18 Systems Research Aircraft (SRA). The EHA is a prototype of similar electrically powered flight-control actuators that promise to significantly reduce the weights, costs, amounts of needed logistical support, and amounts of needed maintenance of future aircraft.

The EHA operates the left aileron in

the F/A-18 aircraft, without use of a conventional hydraulic system that would ordinarily power multiple hydraulic mechanisms in the aircraft. The EHA includes a hydraulic subsystem that contains a small (in comparison with a conventional hydraulic system) amount of hydraulic fluid. Taking its signals directly from a flight-control computer in the aircraft, the EHA uses electrical power generated by the aircraft engines to drive the pump in its hydraulic subsystem.

For many years, NASA, the U. S. Air Force, and the U. S. Navy have sought to eliminate sophisticated but heavy hydraulic systems in aircraft in favor of electrical "power-by-wire" systems for operating flight controls. Besides reductions in weight, cost, and the amount of needed support, the incorporation of such electrical systems eliminates the need for hydraulic lines in fuselages and wing boxes, thereby diminishing vulnerability in combat. The power-by-wire arrangement will also reduce complexity and increase reliability.

A major milestone on the road to an all-electric airplane, the EHA offers the potential to eliminate or minimize dependence on pneumatic, hydraulic, and related mechanical systems during flights of future aircraft. The EHA and systems related to the EHA could lead to fuel saving between 5 and 9 percent on an all-electric passenger airplane, a reduction of 30 to 50 percent in the amount of needed ground equipment, a reduction of takeoff weight by 600 to 1,000 lb (270 to 450 kg), and a 14-percent reduction in the portion of the area of a military aircraft that is vulnerable to such threats as small-arms fire.

The U. S. Air Force Wright Laboratories (in Ohio) managed the overall EPAD EHA program. Contractors included Lockheed Martin (Binghamton, New York), which was responsible for the EHA electronic circuits and other components; Vickers Electro-Mech (Wichita, Kansas and Jackson, Mississippi), for the pump and motor; Dynamic Controls Incorporated (Dayton, Ohio) for the power-control unit and interface control electronics; and Dowty Aerospace (Los Angeles,

Figure 1. This **Flight-Control Actuator** comprising an electrohydrostatic actuator and electronic controller are used to operate the left aileron in the F/A-18 Systems Research Aircraft, without need for the usual central aircraft hydraulic system.

Figure 2. **Flight Tests** of the flight-control actuator in the F/A-18 Systems Research Aircraft were begun in January 1996.

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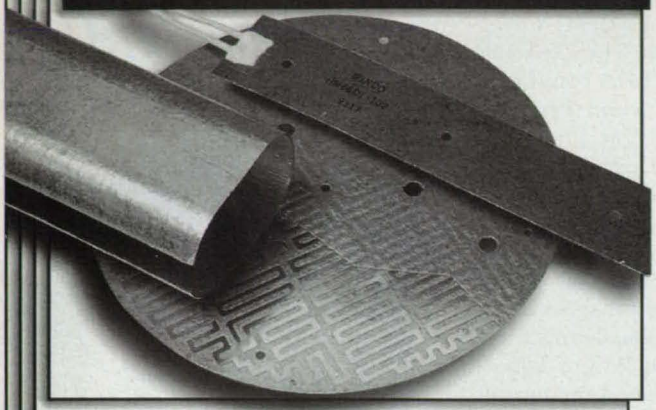

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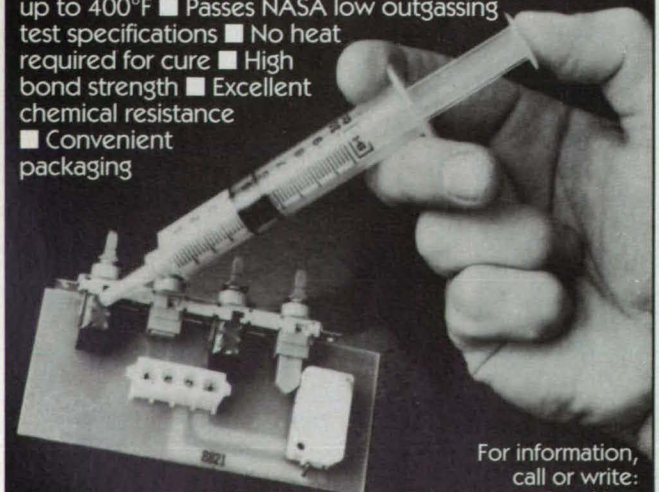

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California) for the assembled actuator. Dryden Flight Research Center performed ground testing, installed and integrated the EHA in the SRA, provided the necessary data-acquisition systems, and was responsible for flight safety.

The EHA is the second of three actuators to be tested under the EPAD program. In May 1993, Dryden Flight Research Center first flew the SRA with a "smart" actuator sponsored by the U. S. Navy and built by H. R. Textron. The third actuator is an electromechanical one that Dryden will fly on the SRA at the end of 1997.

This work was done by Gordon Fullerton, Harry Miller, Robert Navarro, Mauricio Rivas, Joel Sitz, Bob Varanai, and Eddie Zavala of **Dryden Flight Research Center;** *Gavin Jenney of Dynamic Controls, Inc.; Dave Dawson of Wright Laboratories; Dennis Trosen of the U. S. Air Force; Sean Donley of the U. S. Navy; and Joe Dutko of Lockheed-Martin. No further documentation is available.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

Bob Webb
Lockheed-Martin
600 Main St.
Johnson City, NY 13790-1888
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Refer to DRC-96-09, volume and number of this NASA Tech Briefs *issue, and the page number.*

Force-Feedback Device for Microsurgery

This device provides an unprecedented combination of accuracy, control, and workspace volume.

NASA's Jet Propulsion Laboratory, Pasadena, California

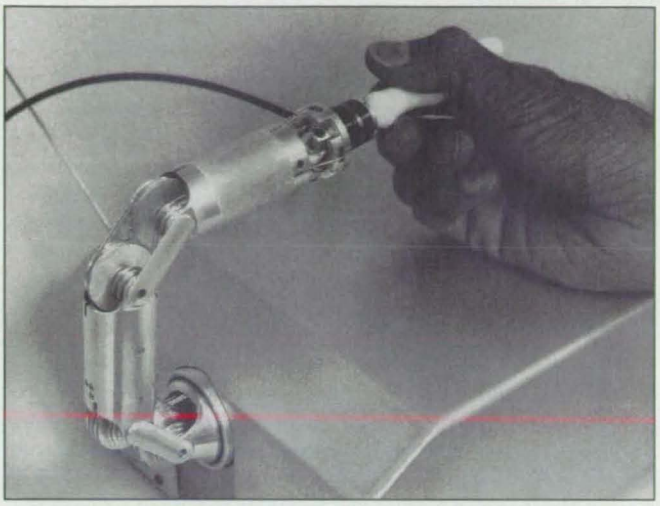
A force-feedback device for robot-assisted microsurgery measures the position of a user's hand with great sensitivity — within 30 μm in translation and 0.07° in rotation. The device acts as the master manipulator in a master/slave system for extremely precise surgical procedures. It currently provides force feedback to the user in 3 axes with minimal inertia and friction but can be configured for 6-axis force feedback. It is compactly packaged and is symmetric for either right- or left-hand operation.

The device is set up to provide a maximum feedback force of 6 oz (1.7 N), although it can produce a force up to 47 oz (13 N) and a torque up to 42 oz-in. (0.3 N·m). It is preferable to minimize the force feedback in order to minimize friction and reflected inertia. It operates in a work envelope of 50-mm diameter.

The device includes a tendon-driven arm that comprises a base, shoulder joint, midarm link, elbow joint, forearm link, and wrist joint. A stylus for user manipulation is attached to the wrist (see figure). Motions along and around the various axes are decoupled from each other by double-jointed, tendon-driven revolute joints described in "Double-Jointed, Cable Driven Robot Arms" (NPO-19361), *NASA Tech Briefs,* Vol. 20, No. 10 (October 1996), page 1b.

The base houses dc brushless motors that drive the joints between the links to create the force feedback on the torso,

shoulder, and elbow axes. Also in the base are six high-resolution optical encoders (40,000 counts per revolution) that measure the positions and orientations of the arm links. The use of high-resolution optical encoders — one for each axis — reduces the amount of gearing needed to achieve the requisite positional resolution without excessive friction.



A Surgeon Manipulates a force-feedback device, which is a master robot arm used to control a slave robot arm that performs microsurgical manipulations. The master arm reflects forces and torques from the slave back to the surgeon's hand.

This work was done by Timothy Ohm of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category,* ***or circle no. 152*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

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Refer to NPO-19822, volume and number of this NASA Tech Briefs *issue, and the page number.*

Rotordynamic Seal and Bearing Tester

This tool advances seal bearing technology through demonstration in a realistic environment.

Marshall Space Flight Center, Alabama

A rotordynamic seal and bearing tester (RSBT) has been developed to provide seal bearing data for space vehicles, such as the Space Shuttle and the Reusable Launch Vehicle. This RSBT is an improved version of an apparatus previously reported in "Dynamic Tester for Rotor Seals and Bearings" (MFS-28493), in *NASA Tech Briefs*, Vol. 15, No. 12 (December 1991), page 80.

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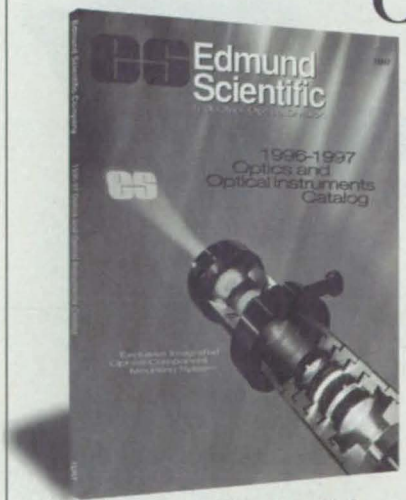

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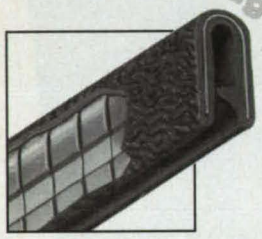
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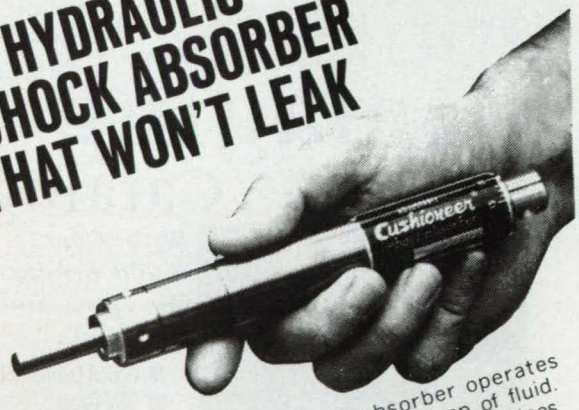

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The RSBT tool was designed to advance seal bearing technology through demonstration in a realistic environment where data are reliably produced to specify the rotordynamics and load-carrying capacity of seal bearings. Previous experience has shown that conventional testers in which test rotors are supported by ball bearings are ill-designed for testing seal bearings.

The rotor of the RSBT is fully suspended on seal bearings that are the very test article from which the rotordynamic data are to be extracted with the instrumentation of the tester. The tester design is based on the same bulk-flow analysis used for the decision to retrofit the high-pressure turbopumps in the Space Shuttle main engines. The instrumentation is a set of reliable proximity probes, readily accessible from outside the tester housing for calibration and inspection. The test rotor is tubular to supply the test seal bearing and the whirl bushing with lubrication without causing axial thrust. The added benefit is a light rotor that has a high resonance frequency outside the speed range of the rotor.

The squeeze film of the seal bearing generates a strong damping effect that makes the tester dynamically inert. The tester and its rotor are coaxially arranged with a stationary center bolt tying the two housing parts together. The bolt, which runs through the bore of the rotor end to the other end of the rotor, has multiple holes in the head to feed the flow from the outside to the rotor bore.

The whirl bushing, which rides on the rotor, is suspended on its own duplex seal bearing. It is lubricated as orifices ooze liquid from the rotor to the duplex seal bearing gaps. The liquid discharges into axial thrust bearings that axially guide on the whirl bushing ends.

The rotor has two separate rings of orifices to feed the two seal bearings of the whirl bushing independently. Two seal bearings form the duplex seal bearing of the whirl bushing. Thus stabilized against tilt disturbances, the whirl bushing freely spins and generates a strong whirl force that eventually squeezes the seal bearings of the rotor.

The whirl bushing, together with turbines, makes the tester leak-proof. This feature is essential for operating with cryogenics and hazardous liquids. The housing completely encloses the rotor and whirl bushing.

The tubular rotor is driven by its turbine at a constant speed. The speed is recorded with pressure and temperature as the test condition for a certain test. Test runs at different speeds are made when investigating the effect of the speed on the rotordynamic parameters of a test seal bearing.

Power for the RSBT is provided through pressurized water or any other working fluid of the seal bearings being tested. Therefore, the facility requires pumps for continuous testing or a blow-down tank for short-duration test runs. The RSBT testing facility consists of a laboratory room, the DSAS, a fluid supply, fluid sump tank, pump speed control, vent valves, electric power, a rack, and a tester pedestal.

The design of the RSBT is unique in its simplicity, low cost, and reliability. This tool should eliminate the long-standing misconceptions about fluid bearings and encourage the design of less costly, yet highly reliable, turbopumps, motors, hazardous-material pumps, jet engines, air-conditioners, and nuclear equipment.

This work was done by George L. von Pragenau of Provident Technology for the **Marshall Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free online at www.nasatech.com*** *under the Machinery/Automation category,* ***or circle no. 110*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*
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LASER TECH BRIEFS

4a Laser Probe for Characterizing Droplets in Clouds

6a Tailored Scattering of Light for Better Illumination

8a Experiments on Growth of GaN on $MgAl_2O_4$

8a Holographic Microtags for Security Applications

10a Optical Correlator Has Adjustable Sensitivity to Translation

11a Fiber-Optic Catheter Probe Would Measure Temperature

DEPARTMENTS

2a News Briefs

14a New Products

On the cover:

Panasonic Factory Automation's Soft Beam Intelligent Machine series for noncontact soldering, called the "SLIM" series, combines energy control, self-monitoring, and other advantages of soft-beam technology in a compact unit that requires only about 10 square feet of floor space, according to the company. *Photo courtesy Panasonic Factory Automation Inc.*

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NEWS BRIEFS

Notes from Industry and the Federal Laboratories

The White House announced that the President intends shortly to name Duncan T. Moore, dean of the School of Engineering and Applied Sciences at the University of Rochester, NY, as associate director for technology of the White House Office of Science and Technology Policy (OSTP). The nomination is subject to recommendation by the Senate Committee on Commerce, Science and Transportation and to confirmation by the full Senate. If the appointment is approved, Moore will take a leave of absence from the faculty and work closely with President Clinton's science adviser, Jack Gibbons.

Moore is an optical engineer and an internationally recognized expert on lens design whose research specialty is the gradient index lens, a sophisticated type in which the refractive index varies along one of its spatial coordinates. In 1980 Moore founded **Gradient Lens Corp.** to commercialize the technology. The company produces high-quality, low-cost borescopes and is developing a new type of medical endoscope.

During the past decade, Moore has played an important role in the modernization of optics fabrication. His research on using computers to guide the design and manufacture of lenses, along with similar work at Eastman Kodak, led to the formation of the University's Center for Optics Manufacturing (COM), created in 1989 jointly by the American Precision Optics Manufacturing Association (APOMA), an industry trade group, the Department of Defense, and universities. Moore has also served as director of the University of Rochester's Institute of Optics.

Precitech, a precision machine business based in Keene, NH, reached conditional agreement in July to be acquired by **Precision Instruments Holdings Limited.** Completion of the acquisition was expected by last month.

Precision Instruments is the holding company for **Taylor Hobson,** a metrology systems designer based in the United Kingdom and acquired from the Rank Organization last year. One of Taylor Hobson's lines is the Pneumo diamond turning machines, which over time will be integrated with the Precitech line of products. Don Brehm, original founder of the company that produced the Pneumo line and current president of Precitech, will remain in that capacity after the acquisition.

The **National Institute of Standards and Technology (NIST)** and **Schott Glass Technologies Inc.** of Duryea, PA, signed a cooperative research and development agreement (CRADA) to study laser-light-transmitting glass and to examine why ultraviolet light changes the index of refraction in optical fibers and bulk glass. Schott will supply novel phosphate glass and silicate rare-earth-doped glass compositions. NIST's Optoelectronics Division will provide waveguide fabrication services and measurement support for waveguide and laser characterization, including optical near-field analysis and mode index, loss, lifetime, and spectroscopic and laser performance measurements.

In addition, the partners will study UV sensitivity of bulk glass samples, striving to understand the physical mechanism responsible for UV - light-induced index of refraction change in glass. Schott will provide glass samples and glass chemistry expertise to NIST, which will investigate techniques for measuring the samples' UV sensitivity.

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Laser Probe for Characterizing Droplets in Clouds

Incipient icing of aircraft surfaces could be detected and quantified.

Lewis Research Center, Cleveland, Ohio

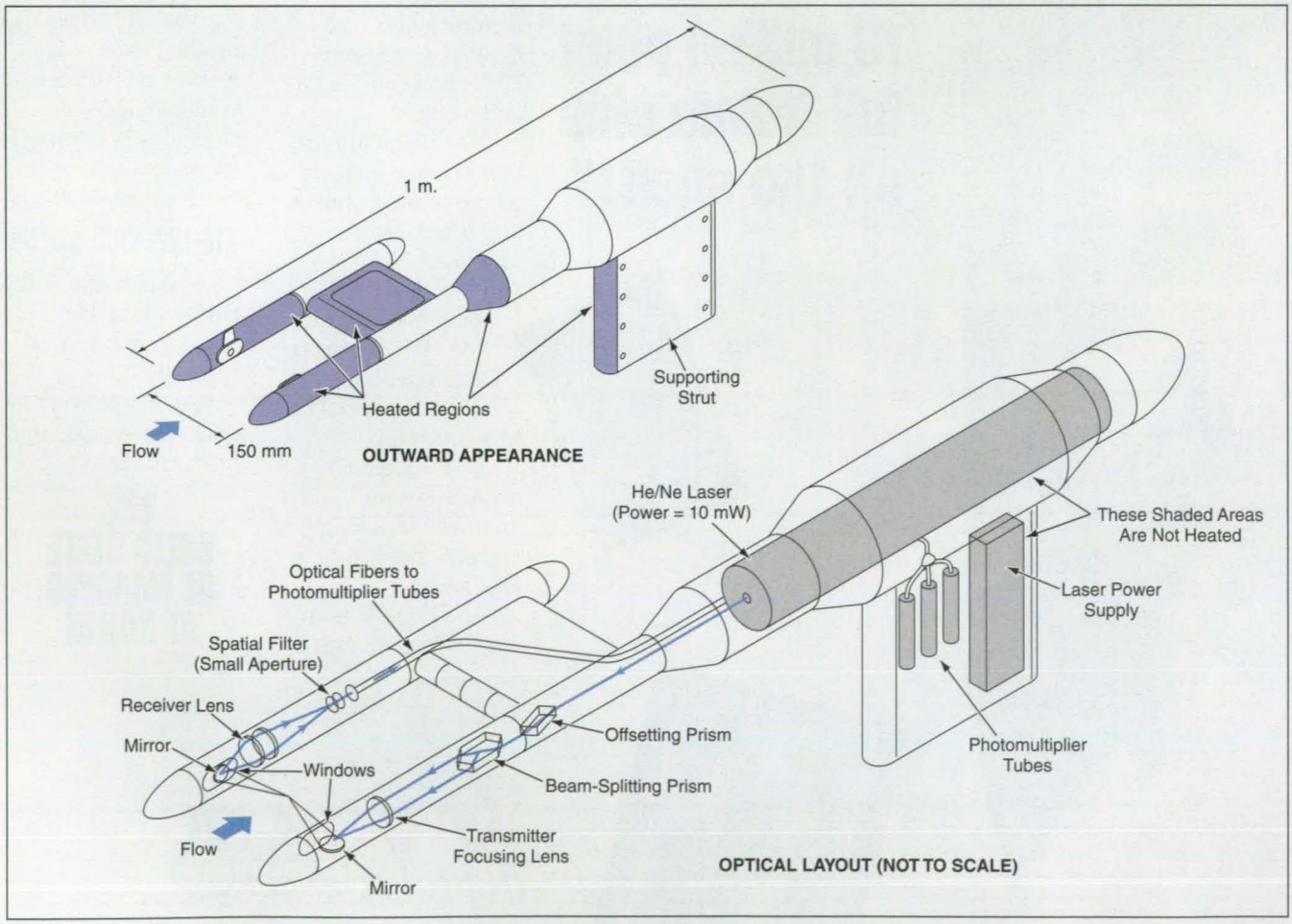
The figure shows the outward appearance and optical layout of a laser probe for measuring water droplets in clouds. This probe is a prototype of instruments that would be mounted on aircraft or used in icing wind tunnels for real-time measurement of droplet sizes (typically of the order of microns) and determination of the liquid water contents of clouds to quantify the potential for accretion of ice on aircraft surfaces. Similar laser probes are used to measure the sizes of solid particles and liquid droplets suspended in flowing gases and liquids in a variety of natural, industrial, medical, and agricultural processes.

This probe is called an "Airborne Droplet Analyzer" (ADA-100), which is based on the phase Doppler technique, which is an extension of the laser Doppler velocimeter technique. As in a laser Doppler velocimeter, a laser beam is split into two coherent beams, which are then made to intersect in a small probe volume, where they form interference fringes. A droplet moving through the probe volume scatters light in a burst of oscillations (called a "Doppler burst") as it passes through the interference fringes. The scattered light includes far-field interference fringes with a spatial interval inversely proportional to the size of the droplet.

Some of the scattered light is focused onto a small aperture. Mounted in precise positions behind the aperture are the input ends of three optical fibers, each of which feeds light to a photomultiplier tube. The outputs of the photomultiplier tubes are fed to a Doppler signal analyzer (DSA), which is capable of processing signal components at frequencies up to 160 MHz. The DSA digitally samples the photomultiplier outputs and performs discrete Fourier transforms to determine frequencies and phases.

By the laser Doppler velocimeter principle, the outputs of the three photomultiplier tubes for the Doppler burst of a given droplet oscillate at the same frequency, which is proportional to the velocity of the droplet through the interference fringes. By the phase Doppler principle, the difference between the phases of the oscillations in the outputs of any two of the photodetectors is proportional to the size of the droplet. Thus, one can calculate the size of the droplet from the phase difference for two photomultipliers. The use of three photomultipliers instead of two extends the range of phase measurements and thus droplet sizes that can be determined, affords some redundancy for verifying calculated droplet sizes, and provides a basis for rejecting spurious signals from scattering by ice crystals.

To characterize a cloud, it is necessary to accumulate data from many Doppler bursts to obtain, among other



This **Laser-Based ADA Probe** measures the sizes of cloud water droplets under icing conditions. The regions indicated by shading are heated to prevent icing of the probe.

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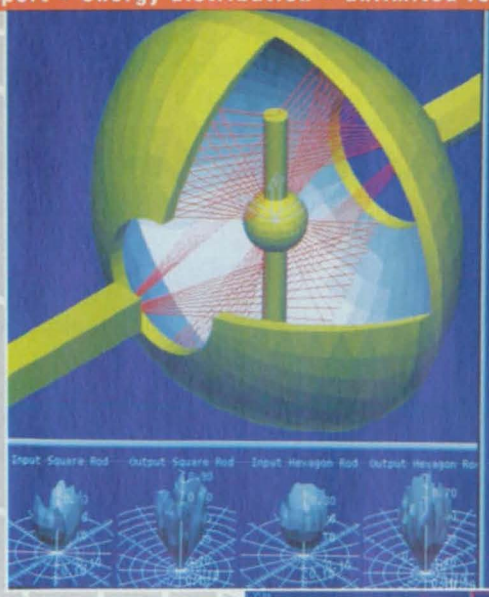

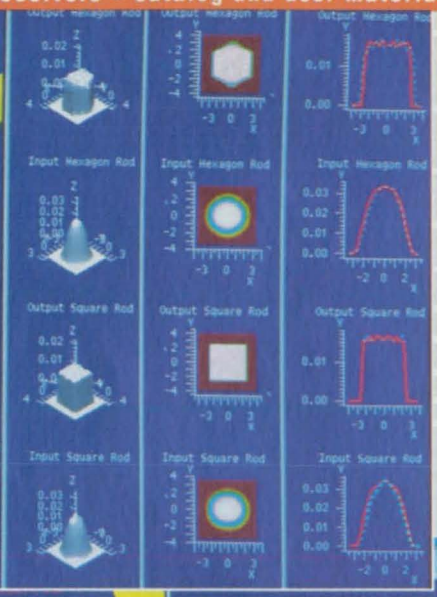

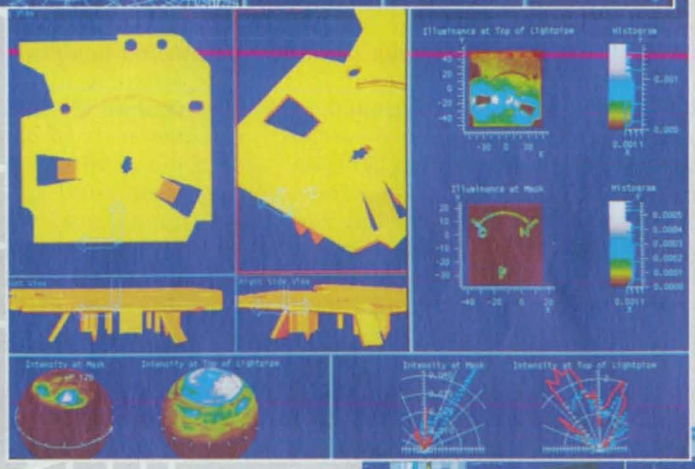

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things, a droplet-size distribution. In interpreting and using the droplet-size distribution, it is necessary to correct for the variation of the probe volume (and thus the sensitivity of the probe) with droplet size. One also needs velocity and frequency-of-droplet-arrival data, along with the droplet-size distribution, to calculate the liquid water content of the cloud.

In tests in the NASA Lewis icing research wind tunnel, the probe has been shown to measure liquid water contents repeatably and accurately within 20 percent of nominal expected values over a wide range of operating conditions. At the time of reporting the information for this article, tests aboard the NASA Lewis Twin Otter research aircraft were planned.

This work was done by R. C. Rudoff, E. J. Bachalo, and W. D. Bachalo of Aerometrics, Inc., for **Lewis Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category,* ***or circle no. 180*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7-3, 21000 Brookpark Rd., Cleveland, OH 44135. Refer to LEW-16158.

Tailored Scattering of Light for Better Illumination

Sources of light would appear to be spread nearly evenly over larger areas.

Lyndon B. Johnson Space Center, Houston, Texas

Two types of light-scattering devices have been proposed to make artificial illumination more nearly even and diffuse, as many people seem to prefer. The general concept of using light-scattering devices to make artificial illumination more comfortable is not new: what is new are the specific proposed design concepts for light-scattering devices, which may prove to be more effective for the purpose than prior light-scattering devices have been.

In designing light-scattering devices for artificial illumination, the effect that one seeks to achieve is to make each source of light (incandescent or fluorescent bulb) appear to occupy an area much larger than its actual size and to emit diffuse light evenly over the much larger area. In the case of multiple sources of light (e.g., a ceiling array of incandescent or fluorescent bulbs), one seeks to make all the sources appear to blend into one source that occupies a substantial area of (or the entire) ceiling and to emit diffuse light evenly from the entire area.

According to one of the two proposals (see Figure 1), the sources in a ceiling array would be connected by a flat translucent sheet made of transparent plastic or glass filled with light-scatter-

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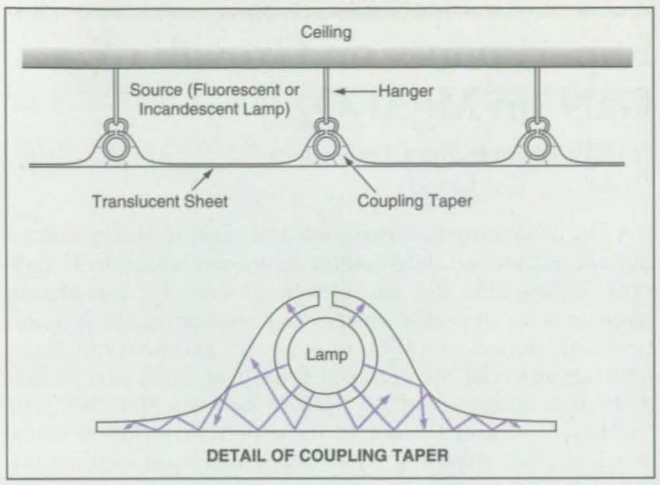

Figure 1. **Light Propagating in the Sheet** by internal reflection would be scattered out, providing diffuse illumination.

ing particles. The light would be coupled from each source into the sheet via a coupling taper that would be integral with the sheet. The coupling taper would provide a transition in light-transmission cross section from the source to the surrounding area of the sheet. The outer surface of the taper would be covered with a thin, partially reflective layer of metal so that light traveling directly from the source through the taper to the space below would be no brighter than the light scattered from elsewhere in the sheet.

The density of the particles would be made to vary with position in the sheet, such that the brightness of light scattered from every point on the sheet would be approximately the same. The needed spatial variation of density could be determined experimentally and/or theoretically.

According to the other proposal (see Figure 2), light would be scattered from both an upper white diffuse reflecting surface (which could be the ceiling) and by a translucent sheet below the sources. Additional layers of translucent material would be stacked under each source in a judiciously chosen pattern to obtain increased diffuse reflection of

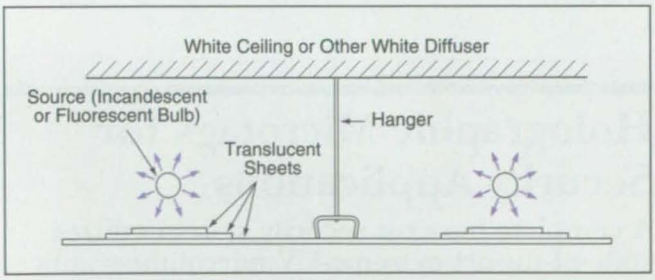

Figure 2. **Additional Layers of Translucent Sheets** would be placed under the sources to obtain additional back-scattering under the sources.

light up to the ceiling in the vicinity of the source. As before, the net effect would be more nearly even illumination of the space below.

Devices of the second type were successfully developed, and they created a very even illumination with equal or slightly less light loss than that produced by standard, discrete, commercial diffusers. A prototype of the first type was also made and evaluated.

This work was done by Hendrik Gerritsen of Advanced Environmental Research Group for **Johnson Space Center.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category,* ***or circle no. 181*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*
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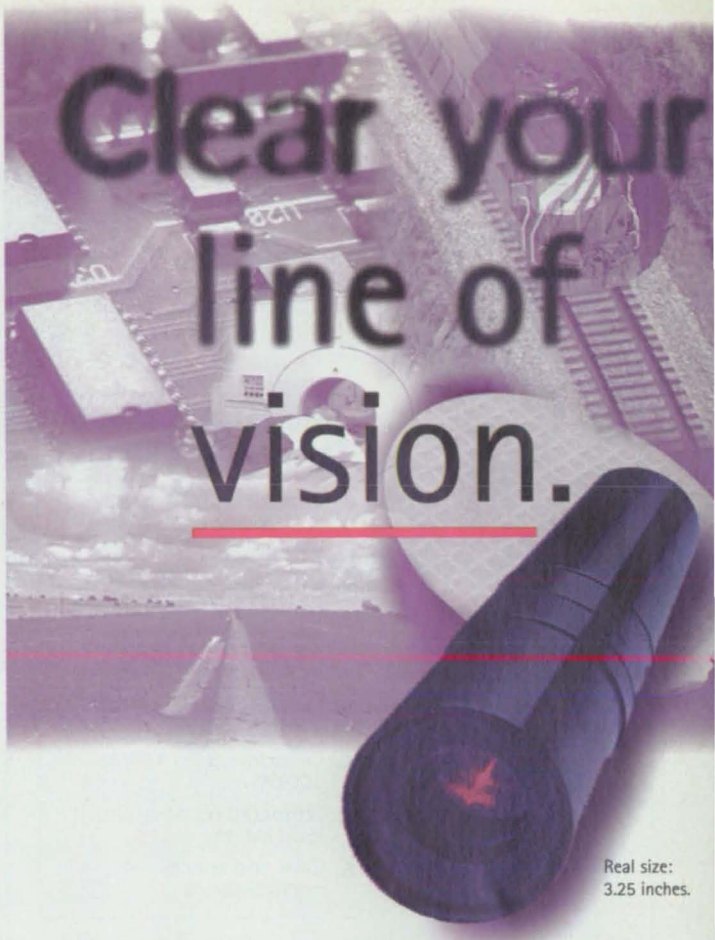

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Experiments on Growth of GaN on $MgAl_2O_4$

NASA's Jet Propulsion Laboratory, Pasadena, California

A report describes an experimental study of the growth of gallium nitride on magnesium aluminate substrates. GaN exists in wurtzite and zinc-blende phases; the zinc-blende phase is more desirable for use as a semiconductor in optoelectronic devices. $MgAl_2O_4$ would be an excellent candidate substrate material for epitaxial growth of GaN, except that there is a mismatch of 10 percent between the GaN and $MgAl_2O_4$ crystalline lattices. In the experiments, low pressure metal/organic chemical vapor deposition from triethylgallium and ammonia source gases was used to grow GaN on (111)- and (100)-oriented $MgAl_2O_4$ substrates, with the expectation that the threefold symmetric (111) $MgAl_2O_4$ substrate would promote the growth of wurtzite GaN, while the fourfold-symmetric (100) $MgAl_2O_4$ would favor the zinc-blende phase. As expected, the GaN film that formed on the (111) substrate was of single-crystal wurtzite, albeit with a high density of stacking faults near the GaN/$MgAl_2O_4$ interface. However, the GaN film that formed on the (100) $MgAl_2O_4$ substrate was not single-crystal zinc blende as expected; instead, the GaN film was found to be divided into five different regions, four of which contained the wurtzite phase in various lattice orientations and one containing the zinc-blende phase. Interfacial bonding, rather than lattice mismatch, appears to play a key role in determining the epitaxial characteristics of GaN films on $MgAl_2O_4$.

This work was done by Thomas George and William T. Pike of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Novel Symmetry in the Growth of Gallium Nitride on Magnesium Aluminate Substrates," access it* ***free on-line at www.nasatech.com*** *under the Materials category,* ***or circle no. 182*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

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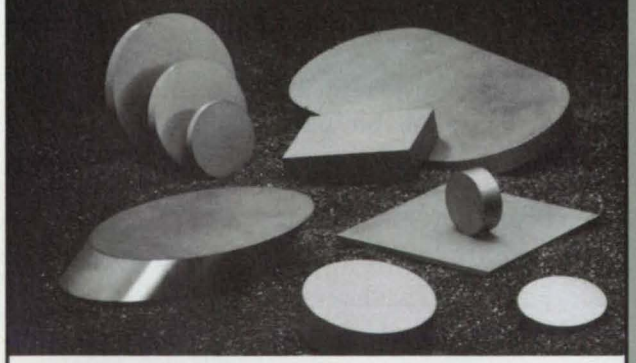

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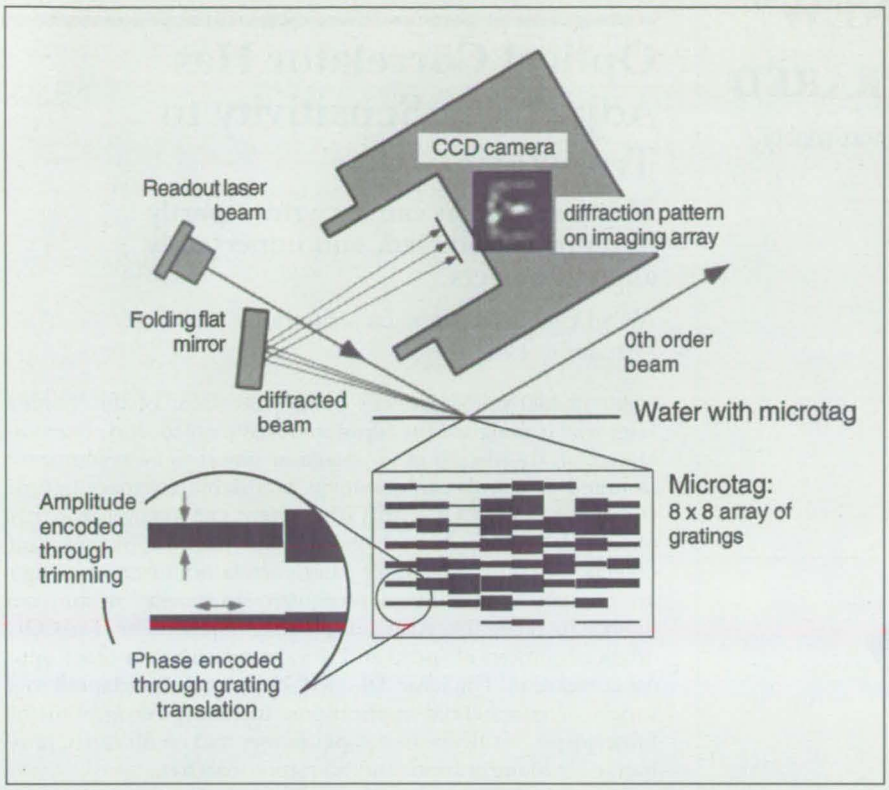
Holographic Microtags for Security Applications

A complete low-cost security system utilizes state-of-the-art extreme-UV microlithography for tagging DRAM chips, microprocessors, CDs, bank cards, etc.

Sandia National Laboratories, Albuquerque, New Mexico

A holographic microtag is a tiny computer-generated hologram (CGH) that measures 56 μm by 88 μm and contains 0.15-μm features. The small dimensions allow a microtag to be easily hidden on a microchip or in a cluttered image on a credit card. When properly illuminated with a laser beam, the CGH forms a distinctive diffraction pattern several centimeters away from the microtag. The complete microtag-readout system consists of a laser diode, focusing optics, and an observation diffuser screen or a CCD camera.

Microtags are arrays of 0.3-μm-period gratings. They are read out with blue light (442 nm) using the geometry shown in the figure. The laser readout beam illuminates a microtag



Readout System Geometry.

at a steep angle. The 64 grating patches arranged in an 8-x-8 array diffract the beam back toward a CCD. With this geometry, the phase at each patch can be changed by moving the corresponding grating a fraction of the 0.3-μm period. The grating is translated perpendicular to its lines (see the figure). The reflectance amplitude of each patch can be reduced by trimming the corresponding grating. Note that phase is produced in one exposure step. This property makes microtags realistically mass-producible. Microtags can be arranged in clusters that require readout from a multitude of azimuth angles. The cluster may be easy to find but it will be difficult to decipher and duplicate, making forgery unprofitable.

A microtag can be designed to form arbitrary application-specific diffraction patterns. These patterns can be alphanumeric characters or abstract pixel codes decodable by a computer. The design process begins with the desired diffraction intensity pattern, such as the letter "E." The next step is an iterative algorithm that ultimately calculates a set of complex numbers that define the microtag. Each complex number represents a reflectance amplitude and a phase. By translation and trimming of the individual gratings, the set of complex numbers obtained by the design algorithm is represented in a microtag.

The research compared a predicted irradiance pattern created by an 8-x-8-patch microtag and the observed irradiance pattern. The pattern had some lumps in it due to speckle. This effect is seen as a "fingerprint," unique to the starting point of the microtag-design process and therefore an added complication to a would-be forger. Furthermore, the introduction of a computer into the microtag system allows automated pattern recognition.

The microtag concept has been demonstrated with a HeNe laser readout source (632.8 nm) and 80-μm-by-160-μm microtags composed of 0.2-μm features. Smaller microtags that measure 56 μm by 88 μm are currently in fabrication. These smaller microtags contain 0.15-μm features and are designed for readout at 442 nm (HeCd laser source). Finally, microtags embedded in a protective polymer medium are in production.

Like any mass-produced item, microtags are not impossible to forge. The advantage of the microtag concept, however, is the relative ease with which a very complex and difficult-to-replicate security feature can be fabricated. The complexity can be adjusted to make counterfeiting of items protected by microtags unprofitable.

This work was done by William C. Sweatt at **Sandia National Laboratories** *and Michael R. Descour at the University of Arizona. For further information contact W.C. Sweatt at (505) 845-8566 or wsweatt@sandia.gov.*

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Optical Correlator Has Adjustable Sensitivity to Translation

This instrument can recognize partly obscured, modified, and imperfectly aligned objects.

NASA's Jet Propulsion Laboratory, Pasadena, California

A compact optoelectronic image correlator of the Vander Lugt type is designed for adjustable sensitivity to, and some tolerance of, translation of an image or object to be recognized. Denoted a "translation sensitivity adjustable compact optical correlator" (TSACOC), this instrument can recognize partly obscured, modified, and imperfectly aligned images and objects. In contrast, Vander Lugt correlators of older design are characterized by fixed sensitivities to translation and are unable to recognize such images and objects. The TSACOC offers advantages of speed and storage capacity over older optical correlators. The basic TSACOC design can be adapted to a variety of commercial applications, including recognition of fingerprints, verification of paper money and credit cards, photographic identification, and literature searches.

The TSACOC includes a laser with optics to generate a collimated beam of light, a spatial light modulator, a multichannel replication holographic element, Fourier-transform lenses, a holographic matched spatial filter (MSF) with an electronically controlled array of shutters, and an array of photodetectors in a classification output plane. Adjustability of sensitivity to translation is achieved by use of a converging reference laser beam.

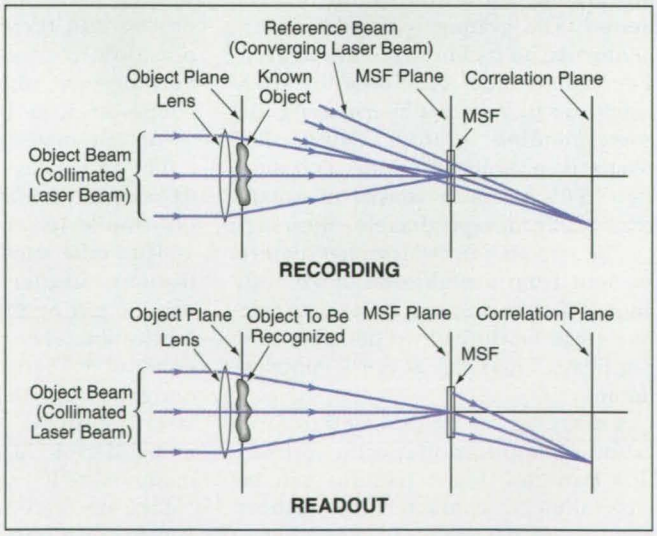

Figure 1. **Recording and Readout in the TSACOC** are performed with similar (nominally identical) configurations. Unlike in other optical correlators, a converging reference beam is used in recording.

In operation in the object-recognition mode, the collimated laser beam passes through the spatial light modulator, which enhances the beam and enters the input image to be identified. The beam as spatially modulated by the image then passes through the multichannel replication holographic element, which contains images of all the known objects to be searched. Continuing on its way, the beam then passes through a Fourier-transform lens to the MSF with its electronically controlled shutters, where a matching function is performed. Finally, the beam as thus processed impinges on the classification output

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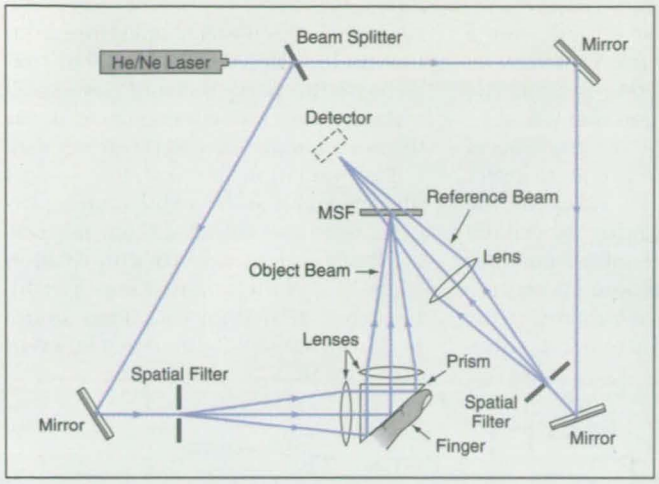

Figure 2. This **Simplified TSACOC** is an experimental prototype of an instrument for recognizing fingerprints.

plane, forming whichever one of the stored images correlates with the input image.

Figure 2 schematically illustrates a simplified experimental TSACOC for recognizing fingerprints. An MSF containing the information on a known fingerprint is made by use of both the object and reference beams, with the known finger pressed against the prism. Thereafter, to verify that an unidentified finger is the same finger as that represented in the MSF, the reference beam is blocked off, and the unidentified finger is pressed against the prism. Experiments have shown that it is desirable to provide a fixture to hold the finger as nearly as possible in the same position in which it was held while making the MSF. A preliminary prototype, which is the size of a suitcase, has been built for commercialization.

This work was done by Hua-Kuang Liu and Neville Marzwell of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category,* ***or circle no. 183*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

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Refer to NPO-19808, volume and number of this NASA Tech Briefs *issue, and the page number.*

Fiber-Optic Catheter Probe Would Measure Temperature

The probe could be used in a human artery.

NASA's Jet Propulsion Laboratory, Pasadena, California

Figure 1 schematically illustrates a proposed multiple-wavelength infrared radiometric instrument with a catheter probe that would be used to determine the temperatures of the inside walls of tubes, cavities, and the like. The instrument could be useful in a number of industrial and biomedical applications; for example, to monitor the temperature of a

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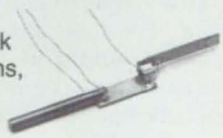

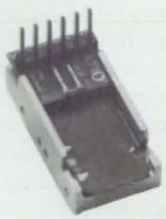

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human arterial wall from within.

The catheter probe would consist of two optical fibers, a guide wire, and a balloon. The fiber-optic tip has a device on the end that gives a radial field of view, rather than a forward view. This allows localization of measurement. One of the optical fibers, called the "signal" fiber, would transmit infrared radiation from the surface to be monitored to the radiometric equipment. The other optical fiber, called the "reference" fiber, would be coated with a reflective material at the probing end and would provide the radiometric equipment with radiation that would be used to compensate for any gradients of temperature along the probe. In order to avoid absorption by water in the blood, as well as scattering by cellular blood components, the measurement is done from within a balloon. An expandable balloon is inflated to contact the artery walls, and the fiber-optic tip measures the balloon-wall temperature from the inside. Since the balloon is in contact with the artery wall and has a small thermal mass and conductance, it has the same temperature as the artery wall.

The radiation leaving the optical fibers would pass through a rotating circular band-pass infrared filter, the pass band of which would vary with rotation angle in a predetermined way. The filtered radiation from each fiber would be detected, then digitized as a function

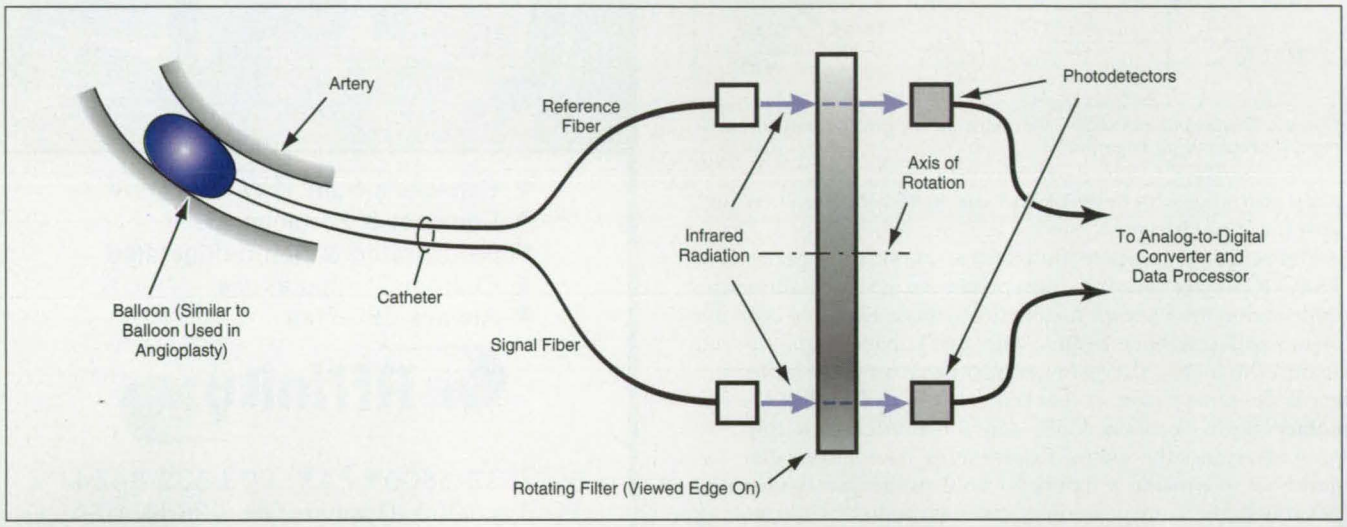

Figure 1. **Optical Fibers in the Catheter Probe** would carry infrared radiation from the probe tip to the radiometric equipment.

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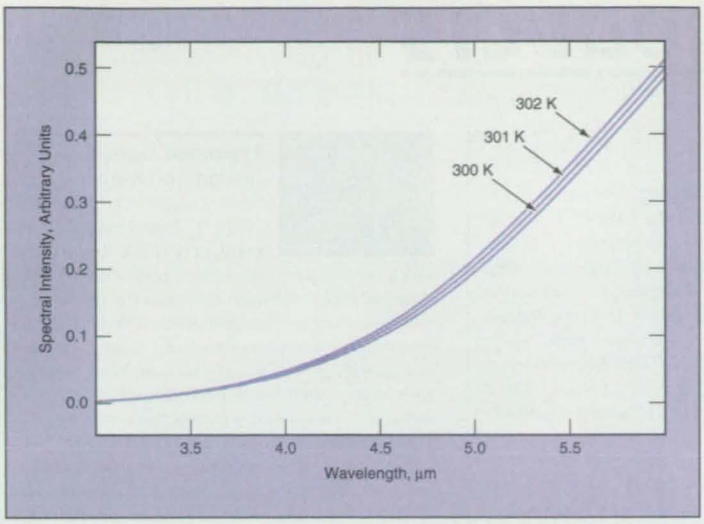

Figure 2. **To a Close Approximation,** the black-body spectra of different temperatures in the range of interest merge at a wavelength of 3 μm; this feature provides a reference for calibration.

of time, then processed to obtain a spectrum from the known relationships among the rotation angle of the filter as a function of time, the nominal wavelength of the pass band as a function of the angle, and the sensitivity of detection as a function of wavelength.

The temperature would be taken to be that of the black-body spectrum that best fit the compensated spectrum from the signal fiber. One of the salient features of the proposed instrument is that it would automatically provide a reference for each black-body spectrum in the biological temperature range of interest (300 to 310 K). It would do this by sampling at a wavelength of 3 μm (in addition to other wavelengths). A reading at 3 μm constitutes a reference because the intensities of all black-body spectra in this temperature range at this wavelength are so nearly equal (see Figure 2) that they can be taken to be equal for the purpose of calibration. This feature "locks down" the low-wavelength side of the spectrum.

This work was done by Gregory H. Bearman, Michael L. Eastwood, and Timothy N. Krabach of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Life Sciences category, or* ***circle no. 184*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

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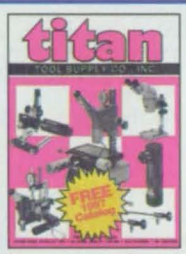

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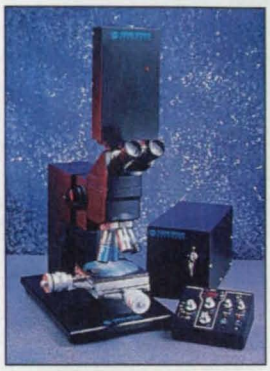


Laser Cutting System for Micromachining

New Wave Research, Sunnyvale, CA, describes the EzLaze™ as a small solid-state laser cutting system designed for semiconductor failure analysis, design verification, LCD repair and other micromachining applications. Available in single- and multiwavelength models that include New Wave's patented Advanced Beam Delivery System (ABDS), EzLaze features single-shot, 1-Hz- or 5-Hz-burst pulse repetition rates. Mounted on the Mitutoyo FS60 or A-Zoom microscopes, it can produce uniform, repeatable cuts ranging from 1 × 1 µm to 50 × 50 µm. Three wavelengths–1064 nm, 532 nm, and 355 nm–are available at the flip of a switch. Energy output is 0.6 mJ; pulse widths vary from 5 to 7 ns depending on wavelength. EzLaze comes with PCLaze™, a Windows interface that allows users to select cut size, triggering, and wavelength through a computer running Windows 95 or Windows NT.

For More Information Circle No. 793

On-Machine Form Error Measurement

The Ultracomp™ on-machine form measurement system from Precitech, Keene, NH, features corrective form error compensation. Measurement is performed with an ultraprecise air-bearing linear variable differential transformer probe mounted next to the cutting tool. The Ultracomp software processes the data, compares it with the ideal surface profile, and after presenting the error on the machine's controller screen generates an error-corrected tool path program that removes repeatable symmetrical errors from the workpiece. Precitech says Ultracomp systems are currently being used in single-point diamond turning and precision grinding.

For More Information Circle No. 795

UV/Visible Light Source

The Novacure™ from EFOS Canada Inc., Mississauga, Ontario, Canada, is a microprocessor-controlled ultraviolet and visible light source capable of providing up to 20,000 mW/cm² of radiant power. A built-in radiometer is removable for calibration to NIST standards. The Novacure is a lightweight unit with adjustable intensity and a high-efficiency cooling system that the company says prolongs lamp life. The "lamp-in-a-drawer" design makes for easy replacement and eliminates the need for focusing, EFOS says. The unit has a switching power supply (90-264 VA).

For More Information Circle No. 798

TE Thermal Reference Source Assemblies

A new addition to the thermoelectric cooler product line from Marlow Industries, Dallas, TX, are Thermoelectric Thermal Reference Source Assemblies (TTRS), hermetically sealed devices consisting of a TE cooler, an emitting surface, and a temperature sensing device which are used in conjunction with control-servo electronics. The company says the assemblies provide high slew rates and low power consumption. Marlow calls the TTRS ideal for calibrating radiometers and forward-looking infrared systems used for surveillance, process control, and "hot-spot" applications.

For More Information Circle No. 801

Single-Mode Connector Compatible with FC/SC

Seiko Instruments USA Fiber Optics Group, Torrance, CA, introduces a new quick fiber optic connector assembly that it says is the only one in the industry compatible with both FC and SC connector styles. The SUP-1 Universal Connector features preassembled, one-piece crimp technology and uses a proprietary funnel-type preradiused ferrule. The connectors accommodate 3-mm, 2-mm, and 0.9-mm fiber types. Insertion loss is less than 0.5 dB typical, and return loss is less than -50 dB typical (Ultra PC polish). Available from stock, the SUP-1 is priced at $6.50 in quantities less than 1000.

For More Information Circle No. 796

UV Microscope for Defect Analysis

Carl Zeiss, Thornwood, NY, says its Axiotron 2 UV microscope is the first to have deep UV (DUV) imaging. Designed for quality control and defect classification of structures below 0.25 micron, the Axiotron 2 UV is optimized for i-line (365 nm) and DUV (248 nm) analysis. A high-resolution scanning stage allows positioning to defect sites using navigation software. The microscope achieves a resolution of less than 0.03 micron per pixel on the wafer within a measurement field of 20 × 20 microns. Objectives include the patented Zeiss DUV Ultrafluar 100x/0.9.

For More Information Circle No. 799

Laser Protective Lenses

Trinity Technologies, Minneapolis, MN, adds to its laser eyewear line Clear View protective lenses that permit the wearer to see all colors of the spectrum when using a ruby laser. A proprietary lens coating provides protection for ruby lasers with an optical density of 6+ at 694 nm and a visible transmission of more than 80%. The filter also provides protection against alexandrite, diode, Nd:YAG, holmium, and erbium lasers. Because the filter allows the wearer to see red, the company says it is particularly useful in medical laser applications where accurate perception of skin color is particularly important.

For More Information Circle No. 802

Expanded Optical Design Software

Optical Research Associates (ORA®), Pasadena, CA, announces CODE V version 8.20, which the company calls a major update to its CODE V optical design software. ORA says the new version has a wealth of new features that enable lens designers to analyze and optimize a wider variety of optical systems with greater power and ease. Many new surface types, such as superconic, thirtieth-order aspherical, compound parabolic concentrator, and 3D cylindrical and circular Fresnel, have been added. Another new capability is analysis and optimization of optical systems using Zernike polynomial coefficients. It is being shipped on CD-ROM for faster installation.

For More Information Circle No. 794

Multi-Channel Dense WDM Laser Source

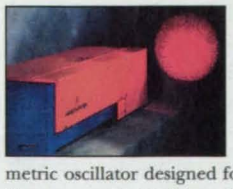
Profile Optische Systeme GmbH, Karlsfeld, Germany, offers the modular PRO 8000 series multichannel laser source for dense wavelength division multiplexing applications. The system, which provides up to 8 channels in each mainframe, can be cascaded, resulting in up to 64 individual channels of stabilized laser radiation in the 1550-nm range. Each source can be custom-selected and spaced according to the ITU-T recommendations. Features include wavelength tuning via temperature and internal modulation, GPIB interface, and drivers for LabVIEW® and LabWINDOWS®.

For More Information Circle No. 797

Low-Noise Laser Diode Drivers

Newport Corp., Irvine, CA, bases its new Series 5000 laser diode drivers on the technology it incorporated in its 6000 and 8000 Series modular controller products. The company says the low-noise, highly stable, high-precision current sources include models with maximum current outputs of 500 mA, 3 A, and 6 A. They feature an internal function generator that is programmable from 200 Hz to 300 kHz with either sinewave or squarewave output, providing a means to generate datacom and telecom test tones for system evaluation.

For More Information Circle No. 800



Optical Parametric Oscillator

The ScanLine-S™ from Lambda Physik, Ft. Lauderdale, FL, is a solid-state optical parametric oscillator designed for the 355-nm output of the company's StarLine diode-pumped solid-state laser. The compact system offers tunable output from the visible through the near-infrared (410-2500 nm), with TEM_{00} mode quality. The company says that unlike traditional OPO/pump combinations that offer low repetition rates only, StarLine makes possible operation of ScanLine-S at up to 1 kHz. Specially coated resonator mirrors allow the OPO to be tuned over the entire spectral range without any change of optics.

For More Information Circle No. 803

Holographic Lithography With Phase Feedback

Better gratings can be made at lower cost.

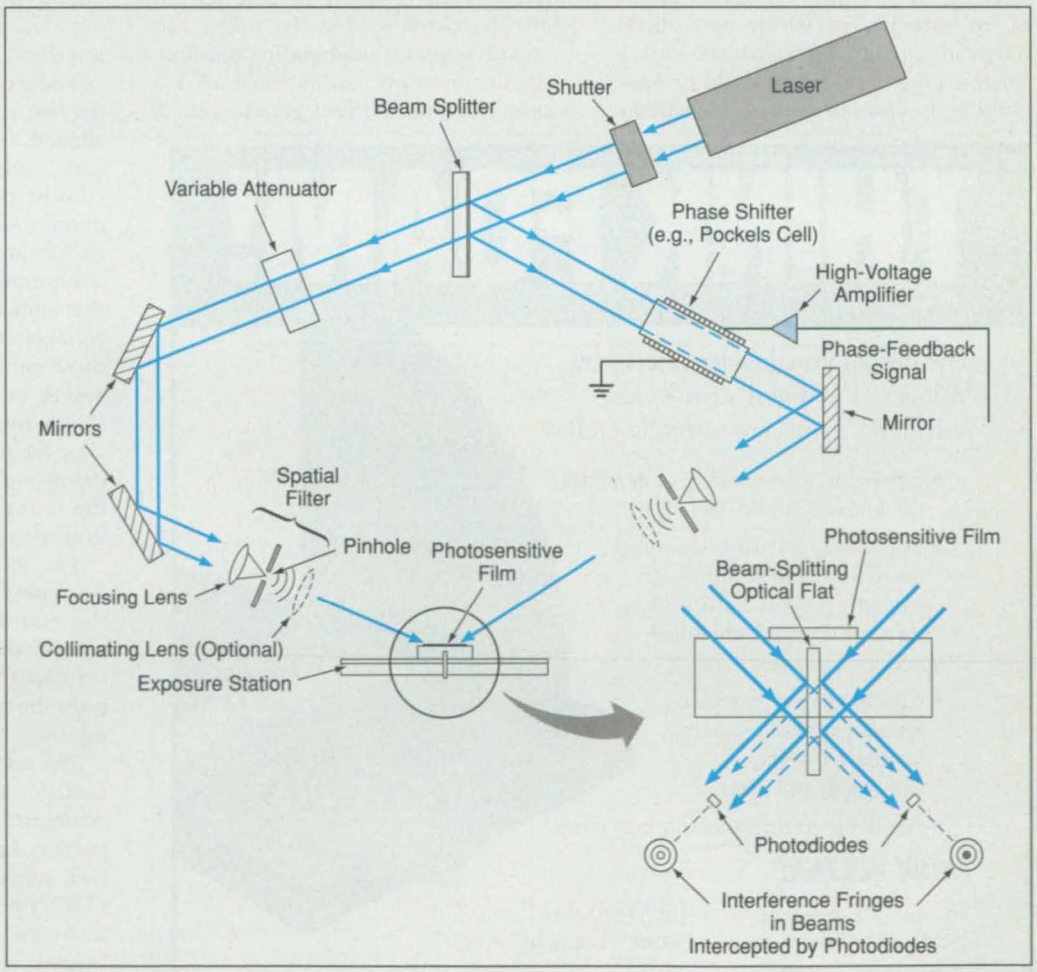
Marshall Space Flight Center, Alabama

Phase feedback can be used to stabilize interference fringes in holographic lithography. For decades, holographic lithography has been used to make precise gratings for scientific and industrial applications. The figure schematically illustrates a typical interferometer used in holographic lithography, with or without phase feedback. A laser beam is split into two beams, which are reflected and spatially filtered to produce two beams with spherical or planar wavefronts that impinge on an exposure station. A variable attenuator is used to adjust the irradiance of one of the beams to make the irradiances of both beams equal (this adjustment maximizes the achievable fringe contrast). A photosensitive film (e.g., a photographic emulsion or a photoresist on a suitable substrate) is mounted on the exposure station, where it is exposed to the interfering laser beams.

In the absence of deliberate stabilization measures, mechanical vibrations of an interferometer used in holographic lithography give rise to fluctuations in the relative phases of two interfering laser beams, causing the interference fringes to oscillate. This oscillation degrades the quality (in particular, when averaged over the exposure time, it degrades the contrast) of any grating that one attempts to make by use of the interference fringes. Heretofore, it has been standard practice to attempt to stabilize the fringes by mounting the interferometer on a high-quality vibration-isolation table. The present technique using phase feedback is potentially more effective for stabilizing the fringe pattern in space and time, making it possible to produce larger, higher-contrast gratings while using a vibration-isolation table of lower quality and thus lower cost.

The present phase-feedback technique involves a beam-splitting optical flat mounted on the exposure station just above (out of the plane of the figure) the photosensitive film. Each of the two beams coming from the left and right is partially reflected from, and partially transmitted through, this optical flat, and the overlapping reflected and transmitted beams on each side is sampled by a photodiode. The overlapping beams are characterized by "bull's-eye" (in the case of spherical wavefronts) or parallel-line (in the case of planar wavefronts) fringe patterns that arise because of interference between the transmitted and reflected beams. In the bull's-eye case, the central spot and the successive rings on one side tend to darken, while the central spot and the corresponding rings on the other side tend to brighten.

The difference between the two bull's-eye patterns depends on, and fluctuates with, the fluctuating phase difference between the right and left laser beams. The photodiodes sense the irradiances in the central spots, and thus the outputs of the photodiodes indicate the instantaneous difference between the



This **Interferometric Apparatus** is used in holographic lithography. For phase feedback, the difference between the phases of the right and left beams is measured by use of the two photodiodes positioned at the centers of the bull's-eye interference patterns. A feedback signal derived from the outputs of the photodiodes is applied to the phase shifter to cancel the phase difference.

phases of the two beams. The outputs of the photodiodes are amplified and otherwise processed into a high-voltage signal that is applied to a Pockels cell or other phase shifter in the path of one beam to cancel the phase difference.

This work was done by Eric Hyde Anderson, Henry I. Smith, and Mark L. Schattenburg of Massachusetts Institute of Technology for **Marshall Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Manufacturing and Fabrication category, or* ***circle no. 172*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

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Soldering Parts Together at Precise Faying Surfaces

By capillary action, the faying surfaces are pulled into intimate contact.

NASA's Jet Propulsion Laboratory, Pasadena, California

A special method of low-temperature metal bonding (in essence, a special method of soldering) has been devised for joining two parts at faying surfaces that are required to conform to submicron tolerances. In principle, the method is not limited to joining parts made of a particular material or geometry; however, in practice, the method is likely to be particularly useful for bonding micromachined silicon wafers to form miniature sensors and actuators.

The method is best explained by use of an example in which two silicon wafers are joined at flat surfaces. First, a shallow groove or pit is made at each bonding location in the affected surface of one wafer. The required depth of the groove or pit depends on the specific application and is typically of the order of 1 μm. Part or all of the recessed surface in the groove or pit is coated with a thin layer of titanium/tungsten alloy followed by a thin layer of gold: this layered metal coat is needed because it is wet by a molten eutectic alloy that is to be used as the solder. The entire affected surface of the other wafer, or at least the part of the surface that faces the metal-coated portion of the recess in the first wafer, is similarly coated so that the solder can wet both wafers at the bonding location.

In this example, the eutectic alloy is made of aluminum and germanium. A layer of aluminum 1 μm thick is deposited on part of the coated portion of the recessed surface in the groove or pit. A layer of germanium 0.6 μm thick is deposited on the aluminum. The combined thickness of the aluminum and germanium exceeds the depth of the groove so that the top of the germanium layer protrudes slightly above the wafer surface. However, the combined volumes of aluminum and germanium are chosen so that when they are subsequently melted, the volume of the resulting aluminum/germanium alloy will be less than that of the groove or pit.

The second wafer is placed like a lid on the first wafer with the bonding locations aligned. The wafers are clamped together and heated to a temperature near the eutectic melting point, causing the aluminum and germanium to diffuse into each other to form the molten eutectic aluminum/germanium alloy. Because the molten alloy wets the metal-coated surfaces of the wafers, it spreads out on those surfaces, thereby pulling the two wafers toward each other by capillary action. Because the volume of the molten alloy is less than that of the groove or pit, the spreading and pulling continues until the faying surfaces of the wafers are in intimate contact with each other.

The joined wafers are then cooled. The coefficient of thermal expansion of the eutectic alloy exceeds that of the wafers; therefore, differential thermal shrinkage of the alloy during cooling pulls the two wafers together even more tightly.

This work was done by Frank T. Hartley of Caltech and Paul M. Zavracky of Northeastern University for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Manufacturing and Fabrication category, or* ***circle no. 102*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

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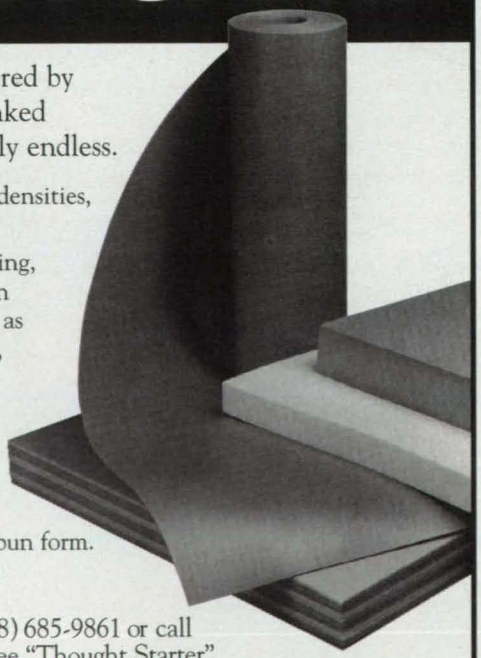

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Soldering Stacked Integrated-Circuit Chips

Connections would be made on broad surfaces and edges.

NASA's Jet Propulsion Laboratory, Pasadena, California

An advanced concept of fabrication and packaging of electronic circuitry calls for soldering and similar thermal bonding to form intimate electrical, mechanical, and thermal connections between adjacent stacked silicon and other wafers, including integrated-circuit chips. The method would provide additional options for designing and fabricating high-density electronic circuits in robust packages.

The concept is a generalization of the method described in the preceding article, "Soldering Parts Together at Precise Faying Surfaces" (NPO-19477). For example, (see figure) eutectic metal alloy bonds in grooves and pits, as described in the preceding article, could simultaneously constitute wireless electrical interconnections, high-thermal-conductance paths for dissipation of heat, and strong mechanical bonds between adjacent chip layers in a stack of chips. Optionally, a suitable plastic could be used, instead of a eutectic alloy, in joints in which thermal and electrical conductance are not required.

Electrical connections through one or more chip layer(s) or through an entire stack could be made by etching holes completely through the affected chip(s) and depositing metal in the holes. Electrical connections could also be made at and across the edges of stacked chips by selective etching and metallization of the edges.

This work was done by Frank T. Hartley of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Manufacturing and Fabrication category, or* ***circle no. 132*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

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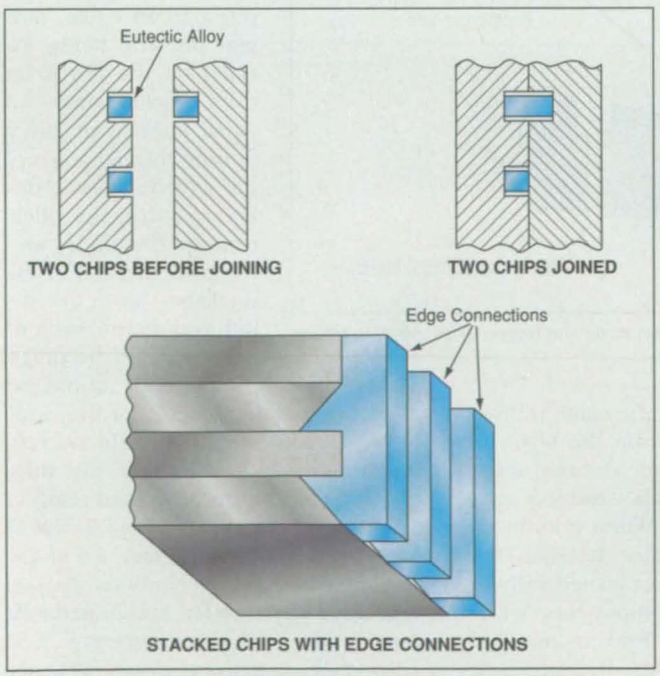

A **Eutectic Alloy** (e.g., solder), placed in grooves in amounts that do not quite fill the grooves, would be used to make electrical, thermal, and mechanical connections between stacked integrated-circuit chips. Electrical connections could also be formed on the edges of stacked chips.

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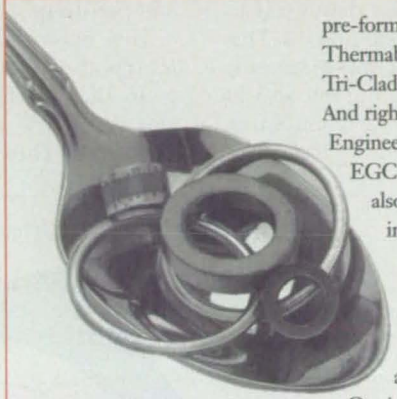

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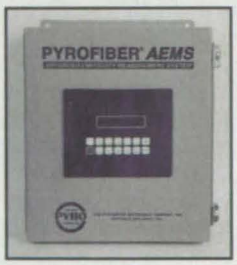

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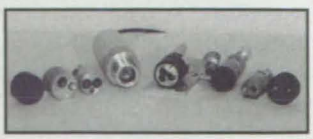

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Fabricating and Testing an Ultrathin Mirror

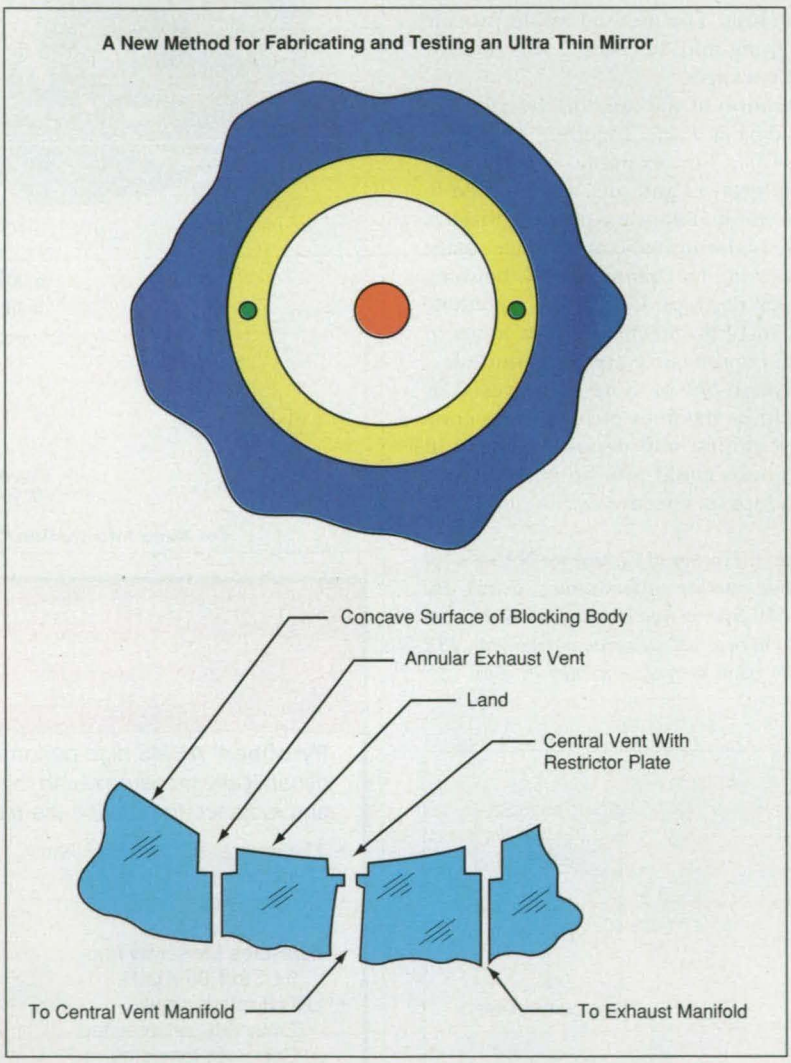
A network of pockets and manifolds minimizes handling and damage risks to mirrors during fabrication and testing.

Marshall Space Flight Center, Alabama

A new method to fabricate and test ultrathin optics has been developed to improve on the traditional process. This method uses a block not only to support the optic during processing but also to support the optic in a nearly strain-free deterministic manner during testing.

The rear surface of the optic (which is larger than the specified dimensions of the finished optic) is ground against the front surface of the block to form matching surfaces. Vacuum, which is applied through a manifold to a network of pockets machined into the block, secures the optic to the block for optical fabrication. For testing, the air is forced through the manifold, floating the mirror on a uniform film of air between the block and the optic.

The network of carefully designed pockets and manifolds is machined into the front surface of the block before it is ground against the rear surface of the optic. Each pocket consists of a central vent, a land, and an annular exhaust vent. Two manifolds are used to connect the pockets — one connects all the central vents, the second connects the annular exhaust vents.



A **Pocket-and-Manifold System** is used during fabrication and testing of an ultrathin mirror.

The mirror blank is firmly attached to the block for machining to near final thickness, fine grinding, polishing, and figuring by applying and maintaining a partial vacuum on both the central and exhaust vents. The annular exhaust vents and the separate manifold are required for subsequent operations when the pockets are used to support the mirror during testing. The partial vacuum, as well as the number, spacing, and pocket design are chosen to minimize the deflection of the optic into the pockets during machining, grinding, and polishing.

This network of pockets and manifolds is also used to supply abrasive slurry to the interface between the optic and the block during match grinding operations. During grinding, a change to a finer abrasive can be made without removing the optic from the block by simply feeding a finer abrasive slurry through the manifolds, flushing away the coarser abrasive. When grinding is complete, the interface between the optic and the block is cleaned without separating the two components. Water or other cleaning fluid is pumped through the manifolds, flushing away any remaining abrasive slurry. If necessary, dry air can be blown through the manifolds to evaporate any remaining cleaning fluids. This *in situ* cleaning reduces the risk to the optic by eliminating the need to lift and handle the optic.

Upon completion of the match grinding and cleaning, the front surface of the optic, attached to the body by vacuum, is machined to near-final thickness, fine ground, polished, and figured.

Support for in-process and final testing of the optic is accomplished by supplying air or a similar gas through the central vent of each pocket. This gas is vented through the annular exhaust ring surrounding each central vent. The airflow through each central vent is controlled by a precision restrictor plate. If the total cross-sectional area of the restrictor plates is small compared to the capacity of the supply manifold and the annular exhaust vents, the air pressure at the inlet of each restrictor plate will be identical. This will result in an equal, normal pressure being exerted on the mirror at each pocket since an equal amount of gas is flowing through each of the orifices. Using this known force, the thickness of the optic, and the configuration of the pockets, the gravity-induced deformation of the optic can be determined and subtracted from the measured figure of the optic to obtain the actual figure. *In situ* testing eliminates handling of the thin, fragile optic and the associated risks.

This work was done by Howard D. Hall of **Marshall Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Manufacturing and Fabrication category, or* ***circle no. 187*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

MFS-31174

Predicting Where Terminated Unpiloted Aircraft Will Land

An algorithm updates estimated ground impact locations in real time for improved safety.

Dryden Flight Research Center, Edwards, California

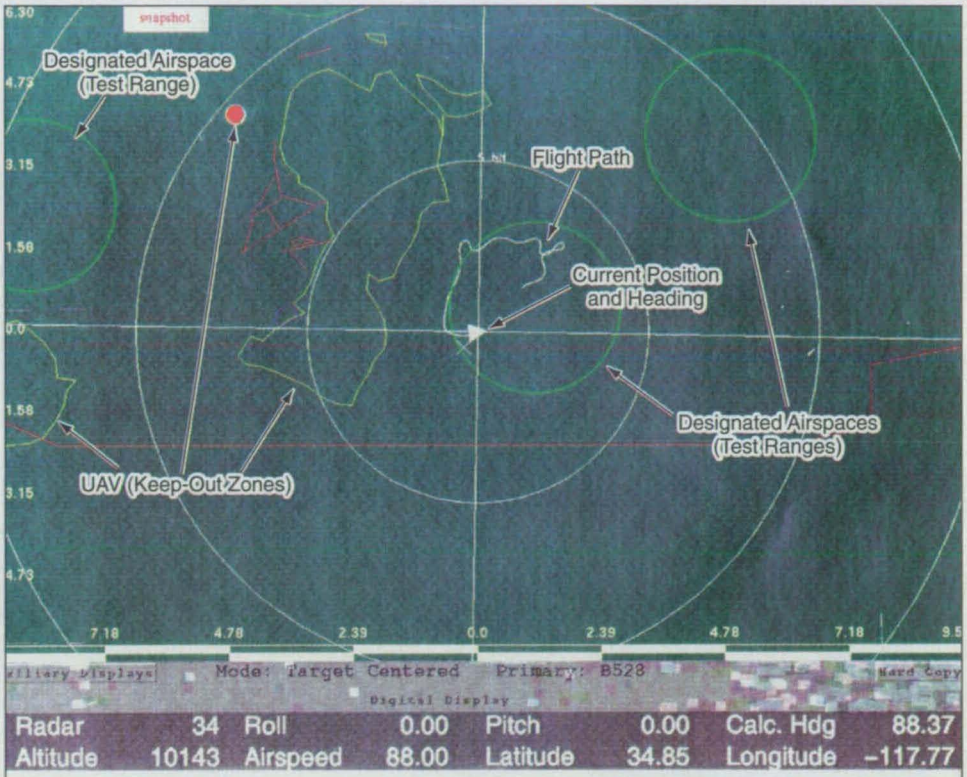
An algorithm has been developed at Dryden Flight Research Center to enhance range safety during tests of unpiloted aircraft [also called "uninhabited aerial vehicles" (UAVs)]. On the basis of current information on winds and an estimate of the rate of descent of the UAV, the algorithm estimates, in real time, the location where the UAV would impinge on the ground if its test flight were suddenly terminated. The predicted location of impact is shown continuously on a range safety officer's moving-map video display so that the flightpath of the UAV can be selected to avoid ground assets (e.g., manmade structures) in the event that the flight must be terminated. The algorithm can be adapted easily to various termination techniques.

Every unpiloted aircraft operating at Dryden Flight Research Center is required to contain a flight-termination system (FTS) to ensure that the aircraft does not leave the designated airspace or range in the event that normal command and control is lost. In addition, the location where the UAV would strike the ground is of concern inasmuch as the designated airspace includes areas of high value. A means of predicting where a UAV will land is critical for real-time flightpath management.

Algorithms in use at other range facilities were designed for high-kinetic-energy aircraft. The need at Dryden Flight Research Center was for an algorithm that could account for low-speed (low-kinetic-energy) aircraft. In addition, the algorithm was required to operate in real time, to be flexible in its ability to account for a variety of termination techniques, and to provide a reasonable estimate of the location of impact.

The moving-map display (see figure) provides continuous information on the present horizontal location, altitude, speed, and heading of a UAV, plus range boundaries and other information. Additional operational boundaries can also be displayed; these boundaries can be designated as UAV keep-out zones. They are typically drawn around ground assets. During the flight, the range safety officer provides guidance to the UAV operator so that the predicted location of impact does not enter any UAV keep-out zone.

The estimate of the location of impact is based on the assumption that the aircraft descends as though under a parachute. Thus, the rate of descent is characterized by a parachute drag coefficient and reference area. The predicted location of impact is a function of the altitude of the UAV, the assumed rate of descent, and the magnitude and direction of the wind. The wind data are critical; they are used by the algorithm to predict the down-range drift during the descent. Wind data are obtained from weather balloons launched



- Areas identified as "Designated Airspaces" are spin areas located within the test range.
- The irregularly shaped regions identified as "UAV (Keep-Out-Zones)" are the boundaries of dry lake beds in the test range.
- The small circle identified as a "UAV (Keep-Out Zone)" is the location of the Dryden radar facility.
- No "Keep-Out" zones are shown in this graphic.
- The line identified by the arrows is the test-range boundary.

The **Moving-Map Display** presents continuously updated information on the present three-dimensional location, velocity, and other flight parameters, and of the estimated location of impact in the event of termination of the flight.

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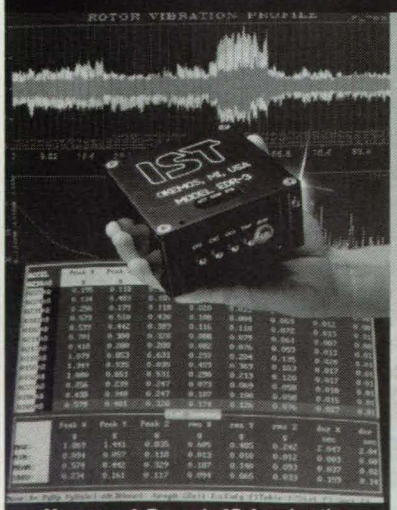

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For More Information Circle No. 454

prior to and throughout the flight of the UAV. In general, the data from the balloons are available in altitude increments of 1,000 ft (305 m). The data are contained in a separate file called the "winds file."

The purpose of the FTS is to keep the UAV within the designated airspace or range. The advantage provided by the algorithm is an ability to make a termination decision with more confidence that the UAV will not drift to an impact in a sensitive area. Indeed, termination can be delayed to enable the UAV to clear a ground asset. Once the FTS has been activated, the algorithm continues to update the predicted location of impact (provided that accurate altitude data are still available).

The algorithm has been adopted by several UAV operators, who use it in their command-and-control stations; this offers the advantage of redundancy with the Dryden control room for protection against a display failure. The simplicity of the algorithm (approximately 240 lines of code) enables its incorporation with even modest equipment. The use of the algorithm greatly increases the flexibility and safety of UAV operations at Dryden Flight Research Center.

This work was done by Jeff Bauer of **Dryden Flight Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mathematics and Information Sciences category,* ***or circle no. 157*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

DRC-97-07

Dynamic Routing for Networks With Random Connectivities

Throughput would be maximized by use of routing along the least populated paths.

NASA's Jet Propulsion Laboratory, Pasadena, California

A developmental algorithm for dynamic routing of messages and assignment of servers in a communication network implements a simple, stationary joint routing and service policy. Unlike a previously developed routing algorithm, the present algorithm is not based on stationarity and precise knowledge of connection probabilities; it is suitable for a network with connectivities and connection probabilities that are unknown and/or that vary with time. When fully developed, the algorithm could be used to increase the capacities of wireless-communication networks, for example.

The routing and service policy and the corresponding basic theoretical version of the algorithm were derived for a mathematical model of an N-node acyclic network with a single input node and a single output node (see figure) and the following other characteristics:

- The basic topology of the network is fixed.
- All jobs enter through the single input node, and there is at most one arrival during any given time slot.
- Each server (node) is always connected to all of its output queues.
- During each time slot, there is some probability that each server is either connected to or disconnected from each of its input queues.

- During each time slot, each server must decide which of its connected input queues to serve and into which of its output queues it should place the completed job.

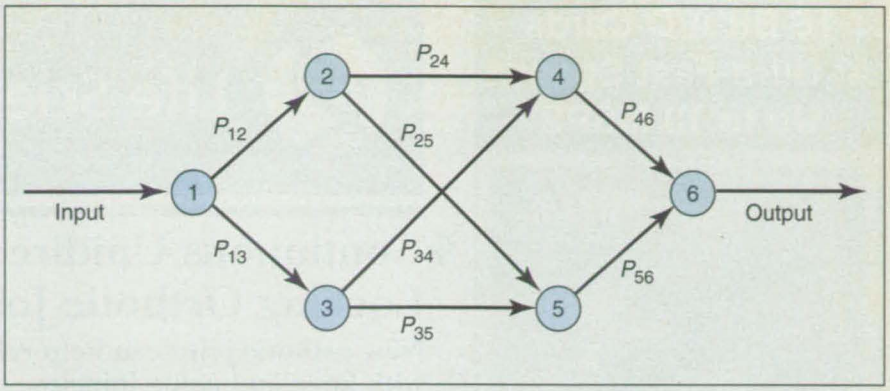
The basic policy and algorithm, implemented independently by each server, is as follows: Upon completion of each job, each server would calculate the number of jobs queued up along every path from itself to the destination and would dispatch the just-completed job along the path containing the fewest jobs. If two or more paths to the destination were equally populated, one would be chosen at random. Each server would always serve whichever of its input queues was the longest according to the most recent calculation.

In performing its routing calculations, the server would utilize queue-length information that it obtained from the rest of the network. This information could be attached, for example, to acknowledgments of receipt of packets of data. Each server must know the lengths of all the queues in the network, but knowledge of connection probabilities is not needed. Thus, the network would respond dynamically to changes in network connection probabilities.

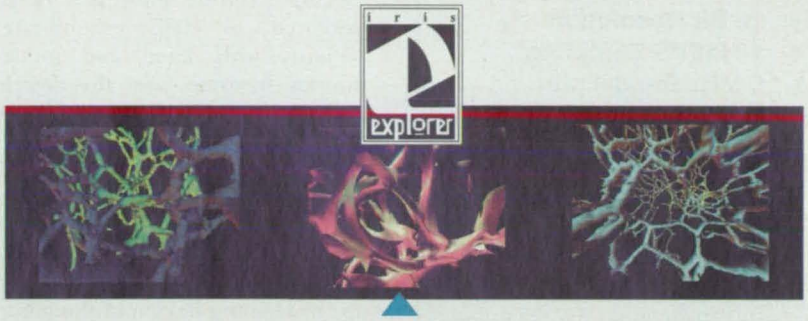
It has been demonstrated theoretically that the foregoing policy and algorithm would maximize the network throughput and result in stabilization of the network in the sense that queue lengths at the intermediate nodes of the network would be stabilized if these lengths were stabilizable at all. In practice, the queue-length information available to each server would not always be entirely accurate and timely; however, it has been conjectured that the stability of the network would be robust with respect to delays in queue-length information. The results of an initial simulation in software have been interpreted as signifying that the algorithm would perform well over a broad range of inputs and under partial or delayed queue-length information.

This work was done by Keith Scott of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mathematics and Information Sciences category,* ***or circle no. 176*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-20188.



This **Single-Input, Single-Output, Six-Node Network** is a simple example of a network with random connectivities. Each symbol P_{ij} denotes the probability that server *j* is connected to the output of server *i* during a given time slot. Each numbered node denotes a server.



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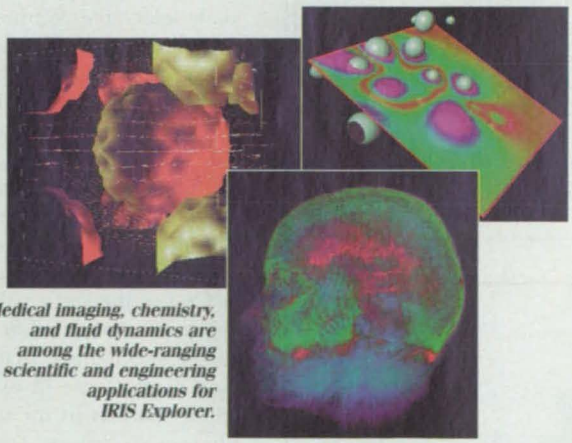

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For More Information Circle No. 436

Continuous Unidirectional Locking Orthotic Joint

New orthotic joint can help rehabilitate patients with knee and ankle injuries.

Marshall Space Flight Center, Alabama

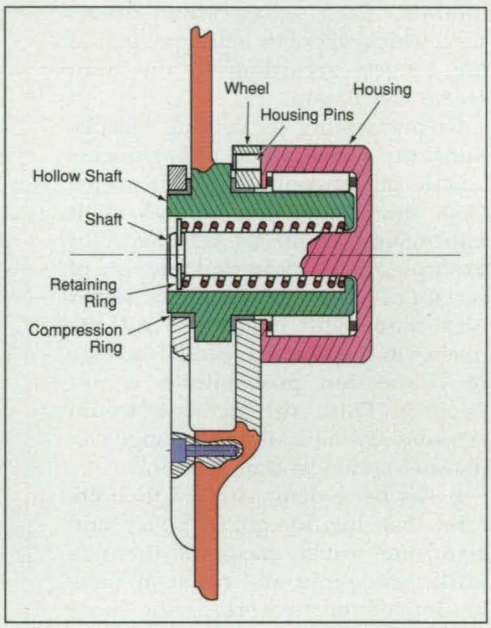
A continuous unidirectional locking orthotic joint has been designed to help rehabilitate patients with knee and ankle injuries. In some cases, this device can also be used during recovery from wrist or elbow injury.

During rehabilitation with the unidirectional locking joint, the patient gradually stretches the damaged joint toward full extension. The orthotic joint aides in this therapy by resisting flexion of the joint, while still allowing extension.

To flex the braced limb, the patient simply releases the locking feature manually. This allows the unidirectional joint to rotate freely through the normal range of flexion. When used for knee or ankle joint recovery, this device also prevents the damaged joint from collapsing because it can bear the full weight of the patient.

This continuous unidirectional locking orthotic joint was designed using a hinge-type joint with a manually selectable continuous locking feature. Two long straps with boltholes allow it to be attached to standard orthotic brace parts. When this new joint is used in the knee area, for example, one side of the hinge joint is attached to the thigh portion of the brace, while the other is attached to the calf portion. Two identical joints are required for this type of application.

One of the principal novel features of this joint, the use of an overriding clutch as the mechanism that allows free rotation in the sense of extension but locks when rotation in the sense of flexion is attempted, can be compared with two similar previously developed orthotic joints. These two joints were discussed in *NASA Tech Briefs* articles "Automatic Locking/Unlocking Orthotic Knee Joint" (MFS-28633), Vol. 18, No. 5 (May 1994), and "Improved Automatically Locking/Unlocking Orthotic Knee Joint" (MFS-27997), Vol. 19, No. 5 (May 1996).



A **Compression Spring** operating inside a hollow shaft locks and unlocks the continuous unidirectional locking orthotic joint by urging the housing and its pins into engagement with the wheel. This spring acts through a retaining ring, which is affixed to the shaft and protrudes from the housing through the hollow shaft.

Another novel feature is the method of controlling the locking and unlocking of the joint. Like the previously developed joints, this device includes an overtravel stop to prevent hyperextension. The configuration of the joint and of the overrunning clutch affords an unprecedented capability for operation without the need for additional connecting members.

This work was done by Bruce Weddendorf of **Marshall Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Life Sciences category,* ***or circle no. 166*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

Inquiries concerning rights for commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center: (205) 544-0021. Refer to MFS-31114.

Motion CONTROL Tech Briefs

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New Motion Control Products — see page 18b

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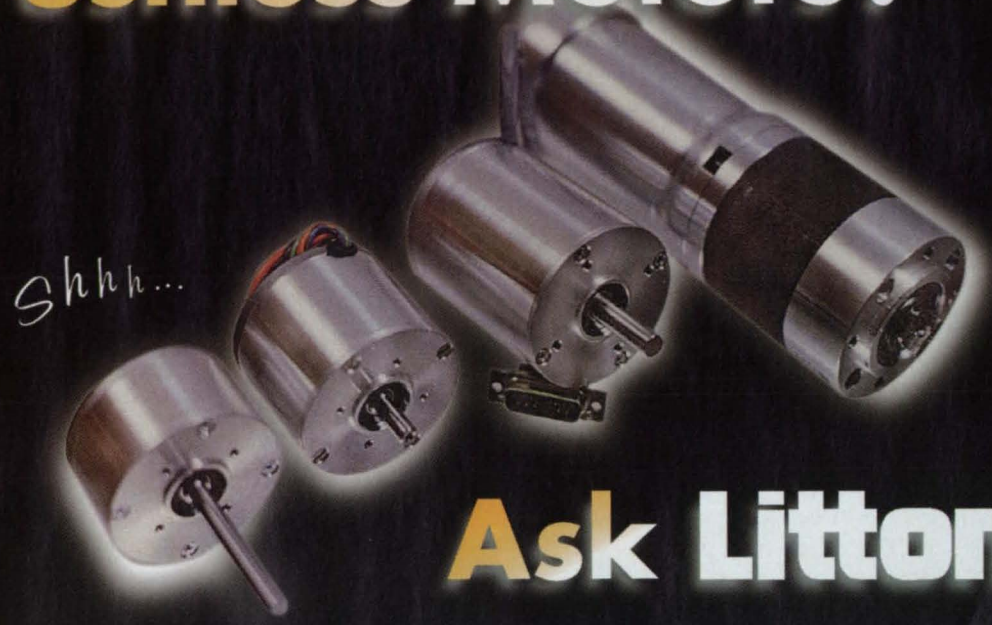

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2b Improved Spherical Gas Bearing

4b Electronic System for Teleoperation of Robotic Vehicles

7b Quantifying Gear Damage by Optimal Tracking of Vibrations

9b Printed-Circuit Board for Driving Multiple Actuators

10b Traveling-Wave Rotary Actuators

11b Motion Control for Laser Soldering

15b Planetary Speed Reducer With Balls Instead of Gears

16b An Interface for Electro-Pneumatic Communications

DEPARTMENTS

18b New Products

On the cover:

The cover shows Clippard Instrument Laboratory's Serial Valve Board with manifolded valves mounted on it. Clippard says this electro-pneumatic interface network device can be used with the company's solenoid valves to provide maximum power and flexibility in operation control. The device's unique features are described in the brief on page 16b.

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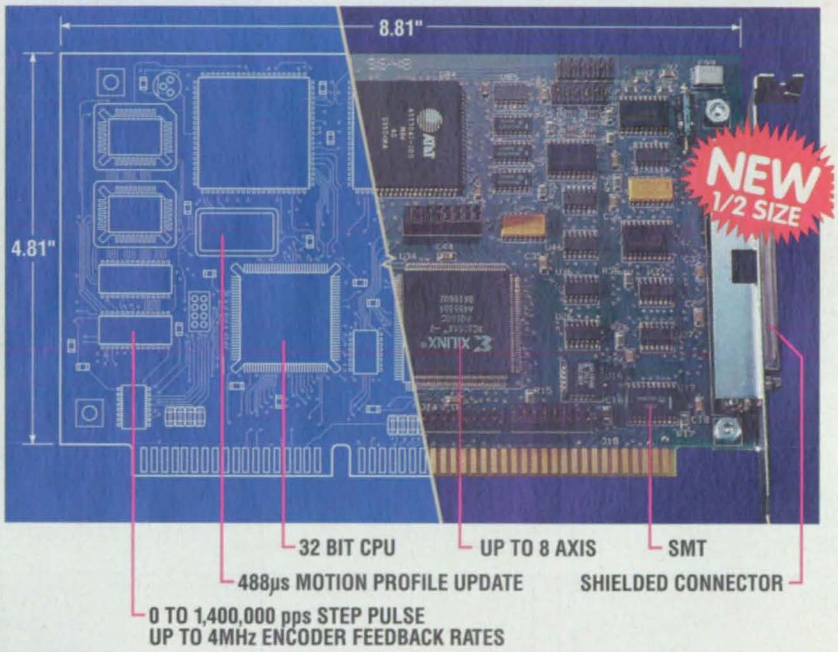

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Improved Spherical Gas Bearing

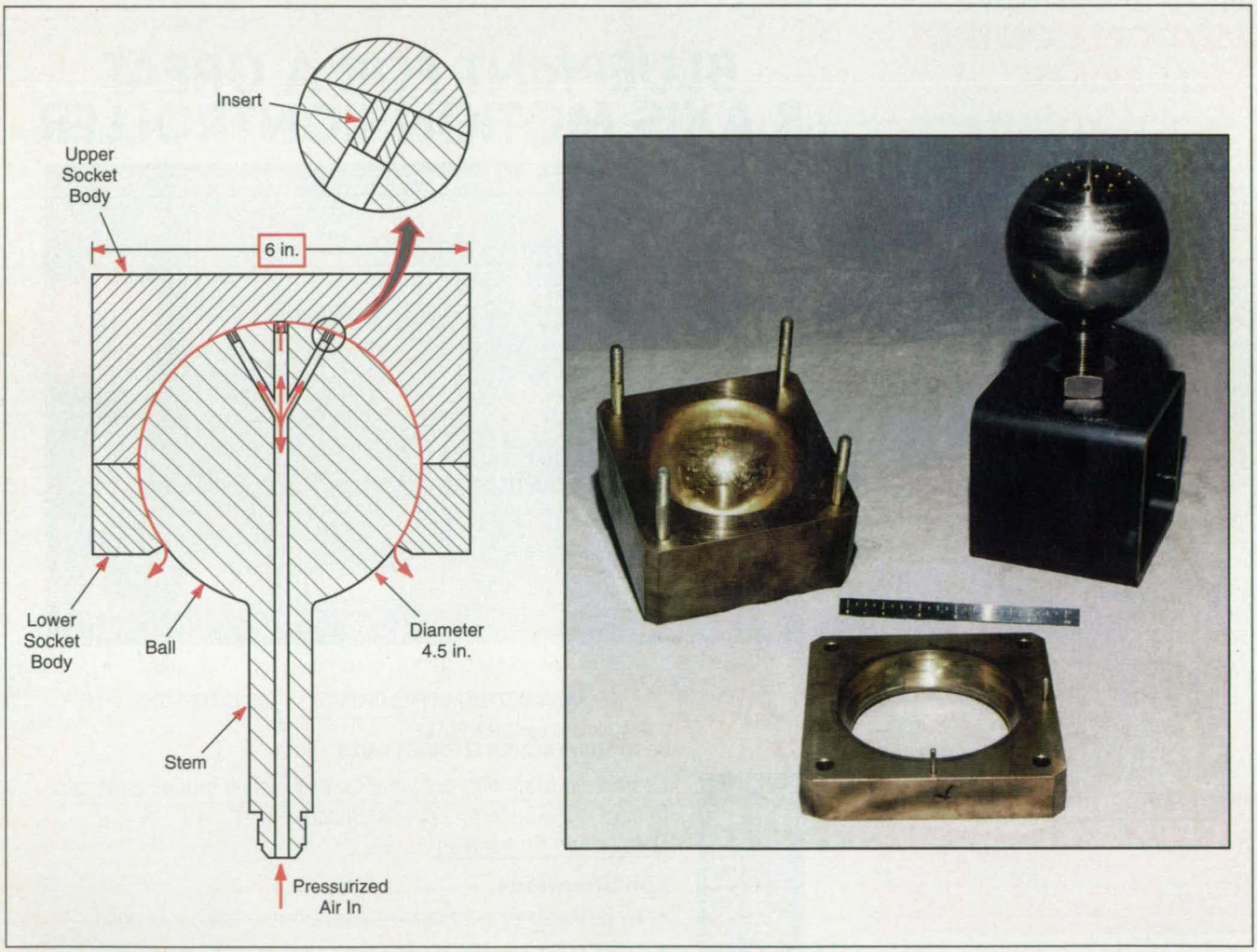
The improved bearing makes a ball-and-socket joint nearly frictionless.

Lyndon B. Johnson Space Center, Houston, Texas

A spherical gas bearing that serves as a low-friction ball-and-socket joint incorporates improvements over older spherical gas bearings. The improvements are such as to create a safer joint that is even closer to being frictionless. Also in comparison with a typical older spherical gas bearing, the improved bearing can be manufactured at lower cost, can be made smaller for the same load capacity, and offers more freedom of rotation. Researchers at the Johnson Space Center use this spherical gas bearing with various satellite mockups to simulate the frictionless conditions of microgravity for crew training. Bearings like this one can also be used in other applications to provide rotational freedom with low friction for large loads.

This spherical gas bearing offers advantages over other means of supporting large loads; such means include magnetic levitation and alternative joints. Both conventional (non-gas-bearing) ball-and-socket and rod-end joints can support large loads, but they exhibit high levels of internal friction. Magnetic levitation relies on sophisticated control systems that consume much power and that induce undesirable eddy currents and magnetic fields. In comparison with the present spherical gas bearing, older types of spherical gas bearings are more expensive to manufacture because they include jeweled orifices in gas passageways that are machined into their sockets. Moreover, unlike the present spherical gas bearing, older spherical gas bearings generally have no provisions to contain their balls in their sockets, so that the older bearings are less safe.

This spherical gas bearing has a basic ball-and-socket configuration and includes three major components: (1) a ball with an integral stem, (2) an upper socket body that contains a hemispherical socket, and (3) a lower socket body that contains a partial continuation of the spherical socket surface and that includes a hole through which the stem passes (see figure). These components can be made from any number of metal alloys or a combination of metal alloys.



This **Improved Spherical Gas Bearing** is basically a ball-and-socket joint lubricated by pressurized air that is injected via holes in the ball. The prototype was made from stainless steel and aluminum bronze.

The upper and lower socket bodies start out as square (viewed along vertical lines) blocks, and the spherical depressions that constitute their bearing surfaces are machined into them, with the center lines of the spheres coincident with the vertical center lines of the blocks. The diameter of the socket is slightly larger than that of the ball. The lower socket body serves mainly to prevent inadvertent separation of the bearing — an important safety consid-

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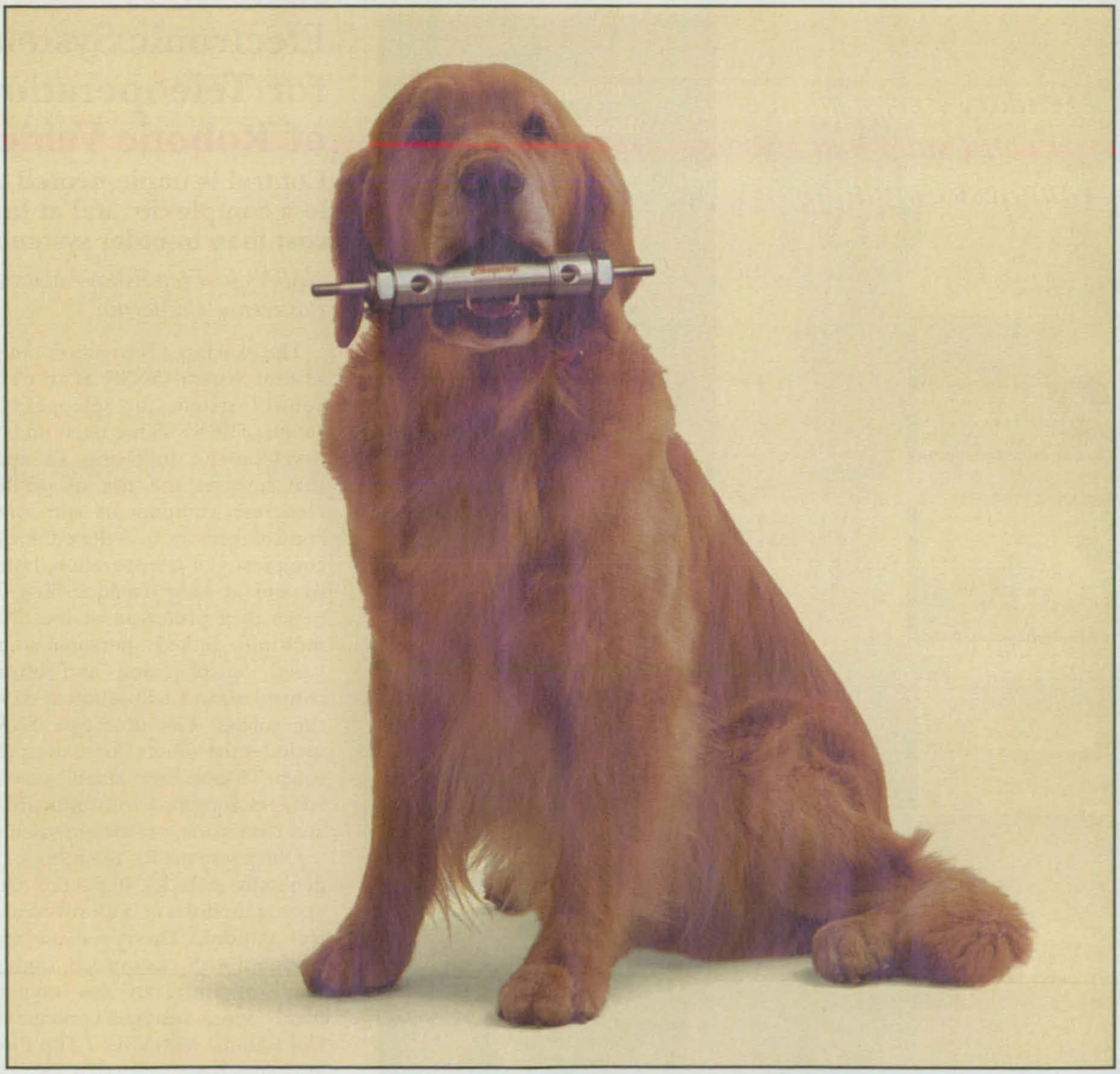

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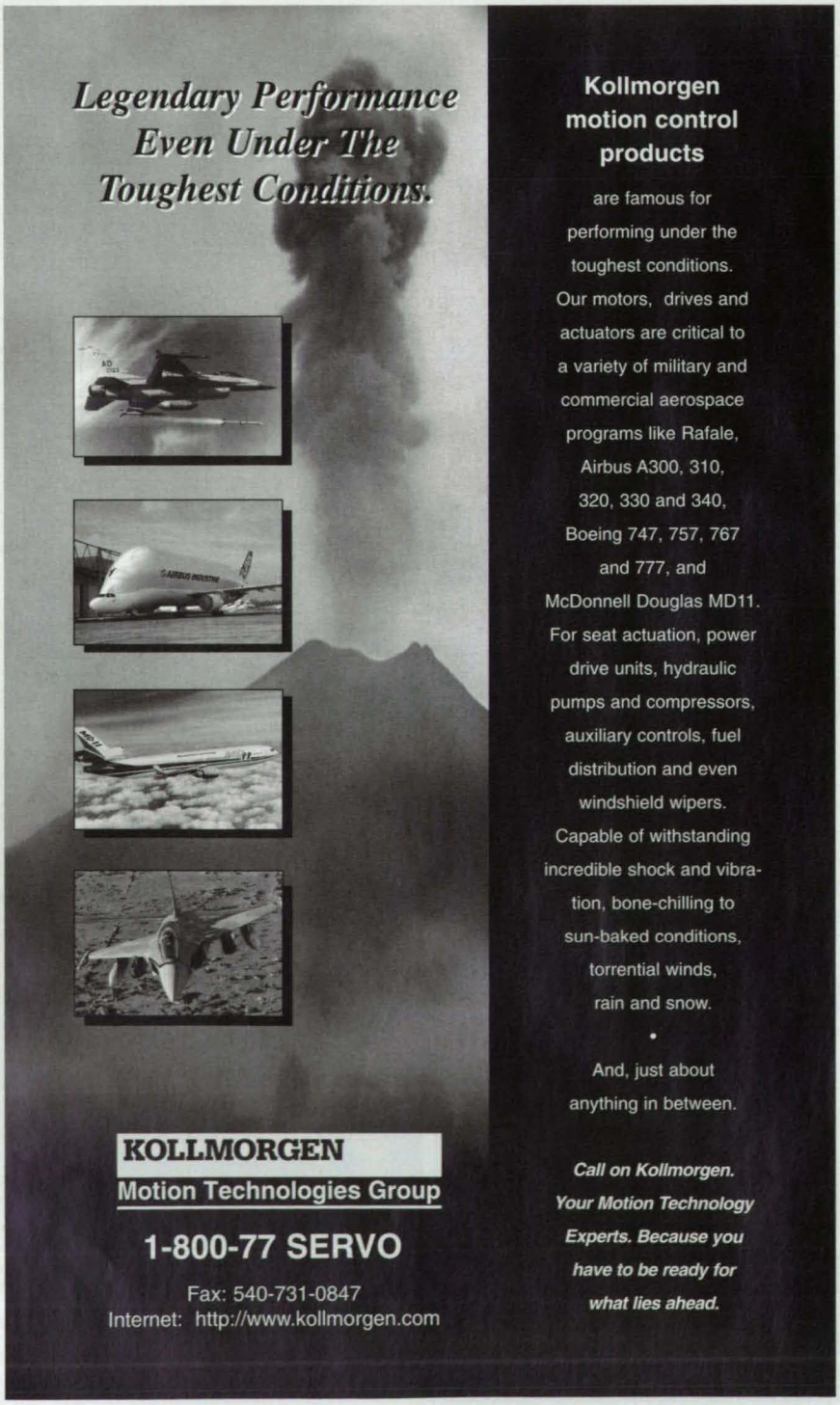
eration in applications that involve interactions with humans. In addition, changes in the mounting of the lower socket body cause changes in airflow patterns and in the level of clearance between the ball and the upper socket body.

The stem is used to rigidly attach the bearing to a mount and to deliver pressurized air to the narrow radial gap between the ball and socket surfaces. A passageway for the pressurized air is machined through the center of the ball and along the axis of the stem. The pressurized air enters through a single orifice at the base of the stem. Near the top of the ball, branch passageways deliver the pressurized air to exit holes, the number and arrangement of which can be chosen to maximize the load capacity of the bearings. The exit holes contain bronze inserts (in place of the jeweled inserts of older designs).

Once the socket is assembled around the ball and pressurized air is supplied, the gap between the ball and socket becomes filled with pressurized air, which exerts an upward force on the socket. When the net upward force of the air equals the weight of the socket plus any attached load, the socket levitates, allowing more air to enter the cavity. The film of pressurized air continues to increase until equilibrium is reached between the pressure and volume of the incoming air and the load on the socket. Traveling fully along the surfaces of the ball/socket interface and then dissipating into the atmosphere, the air serves as a lubricant, centering the socket on the ball and preventing contact between the ball and socket surfaces.

This work was done by Thomas Smith of **Johnson Space Center**. *No further documentation is available.*
MSC-22718



Electronic System for Teleoperation of Robotic Vehicles

Control is implemented with less complexity and at less cost than in older systems.

NASA's Jet Propulsion Laboratory, Pasadena, California

The Surface Navigation and Simulation System (SNSS) is an electronic control system for teleoperation of robots. The SNSS has been undergoing development, following an approach that involves the use of off-the-shelf electronic components and innovative control software to reduce the cost and complexity of teleoperation, both nearby and at long distance. Key components of a prototype of the SNSS are multiple linked personal-computer-based control stations and software for control of, and acquisition of data from, the robots. The prototype SNSS also includes the robots themselves; the prototype robots are small, six-wheeled vehicles equipped with onboard power and data-management subsystems.

Older systems for telerobotic control generally include "high-end" data-processing modules at both rovers and control stations. These systems must be operated with customized, highly complex software. They also require wide-band communications between the control stations and rovers. The foregoing attributes have resulted in high cost and complexity, which have inhibited more-widespread application: In particular, the use of "high-end" computer workstations and sophisticated onboard robot data-processing modules results in high costs of acquisition, even for rough prototype systems. Typically, wide-band communications for control and telemetry rely on expensive satellite links and/or special terrestrial commu-

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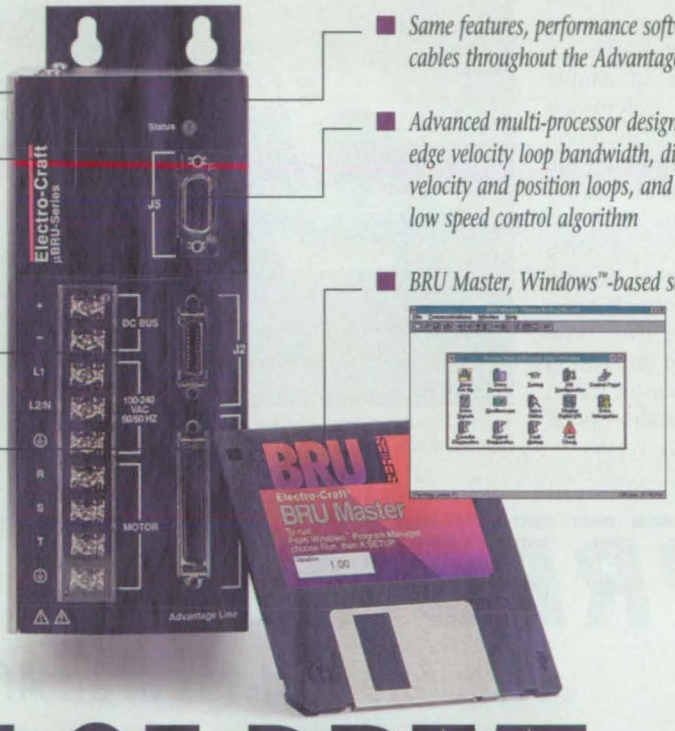

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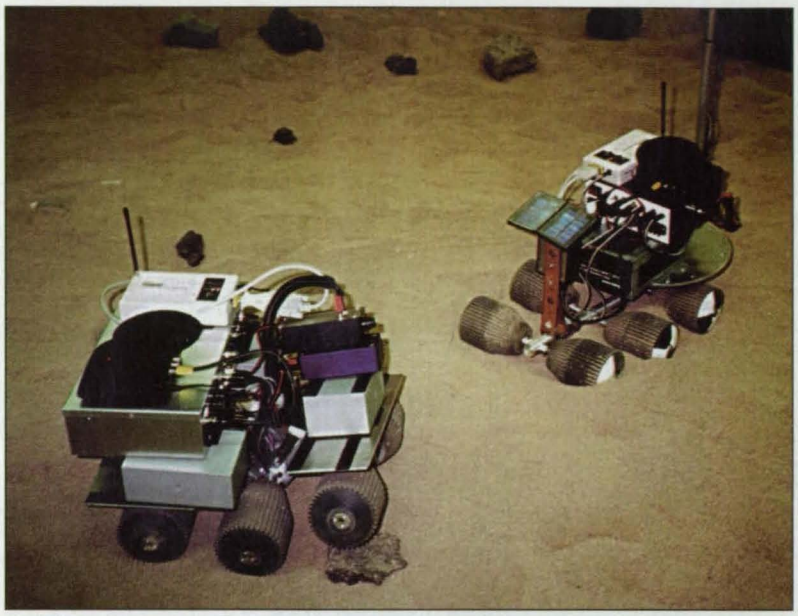
nication lines. Moreover, it is necessary to train operators extensively in the use of the associated software to enable competent operation and interpretation of data received from the robots.

The SNSS operates as an integrated unit. It includes operator-interface hardware and software that enable operators to "drive" the rovers while viewing images transmitted in real time from video cameras mounted on the rovers. The operators also have access to easy-to-read displays of data acquired from other sensors aboard the rovers. A combination of simple radio and telephone links provides communications between the rovers and their respective operators.

The prototype SNSS includes two instrumented six-wheeled rovers (see figure). The capability of the SNSS has been demonstrated in simultaneous operation of both rovers — one in a local operating mode and the other in a remote environment. This demonstration was conducted for intervals as long as two hours without interruption. Images received at the control station from the video cameras were found to be of sufficient quality to support rover navigation. Data received at the control station from other sensor cameras were found to be accurate.

At the time of reporting information for this article, development was continuing and several improvements were expected to be made sequentially during the next two years. One of these improvements would be the incorporation of an "executive" control subsystem that would provide autonomous monitoring and control of robotic devices.



Six-Wheeled Robotic Vehicles carrying video cameras, other sensors, and power and data-management subsystems are operated simultaneously in a demonstration of the SNSS.

This work was done by David Mazaika, Gregory Nemitz, Michael Simon, John Risque, David Mitchell, and Cris Fitch of International Space Enterprises, Inc., for **NASA's Jet Propulsion Laboratory**. *For further information, contact Greg Nemitz, International Space Enterprises, 4909 Murphy Canyon Road, Suite 220, San Diego, CA 92123, Telephone No.: (619) 637-5773.*

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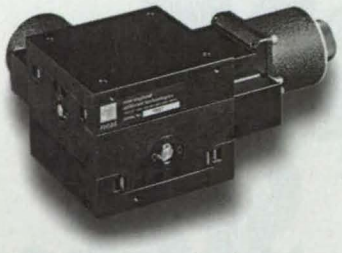

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Quantifying Gear Damage by Optimal Tracking of Vibrations

A one-dimensional mathematical model of gear-mesh dynamics yields useful results.

Lewis Research Center, Cleveland, Ohio

A technique for quantifying damage in gear teeth in a transmission is based on the observation that damage (which can include wear, pits, and fractures) alters the gear-mesh stiffness and thereby alters the vibrations of the transmission during operation. The essence of this technique is to process vibration measurements (instantaneous amplitude as a function of time or gear angle) to estimate the time-varying gear-mesh stiffness and quantify deviations from the periodic mesh-stiffness variations of gears in good condition. The technique involves mathematical modeling of gear-mesh dynamics coupled with nonlinear numerical optimization.

The gear-mesh dynamics are represented by a one-dimensional mathematical model equivalent to the model of a mass m (roughly, the mass of a pinion in mesh with a larger gear) suspended on a spring with time-varying stiffness $k(t)$ and moving in a frictional medium with damping coefficient c. The time-varying spring stiffness is set equal to the time-varying gear-mesh stiffness and represented as

$$k(t) = k_{ave} - k_{periodic}(t) - k_{perturb}(t),$$

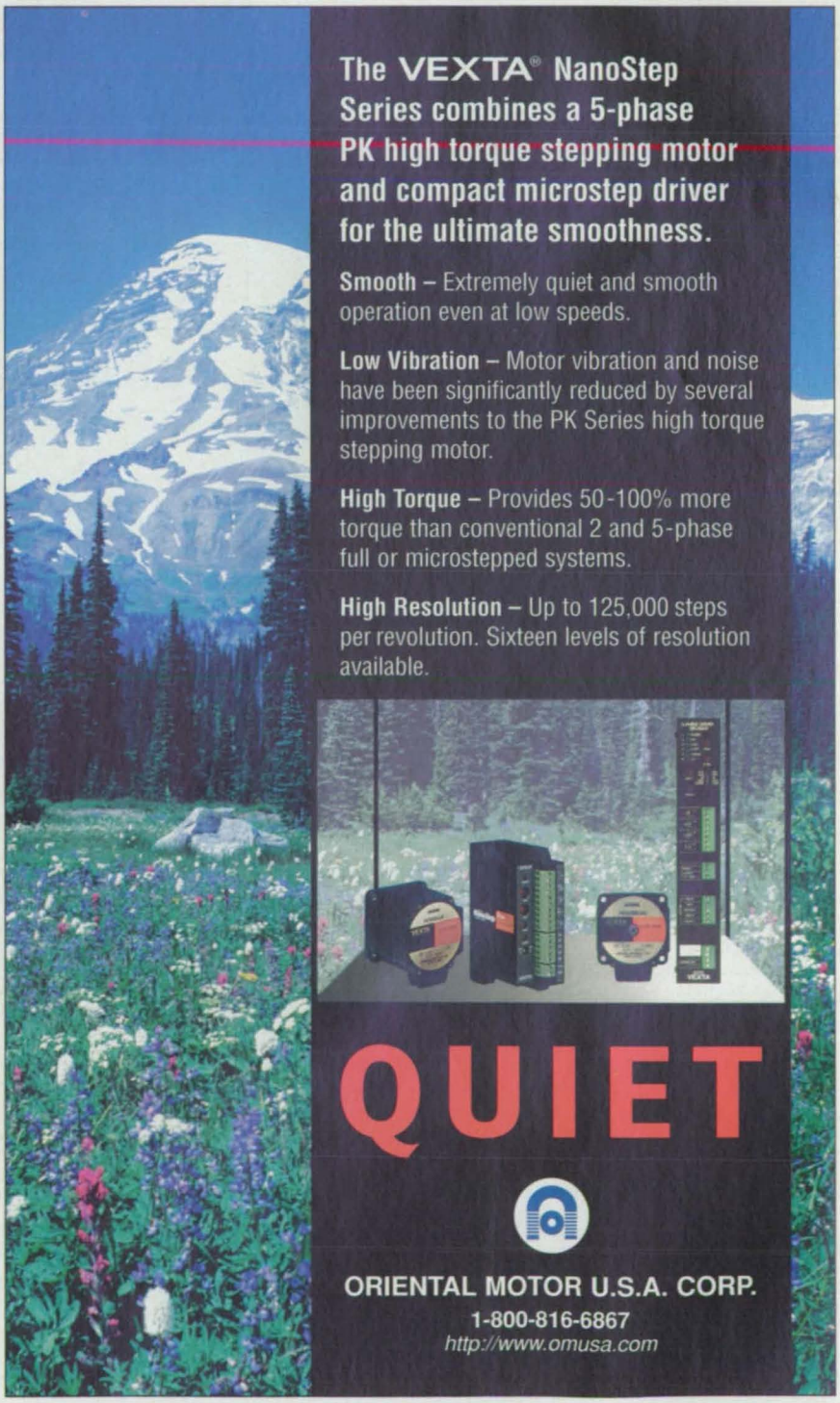
where k_{ave} is a constant or time-averaged component, $k_{periodic}$ is the periodic variation in stiffness of the tooth-pass cycles of gears in good condition, and $k_{perturb}(t)$ is a stiffness perturbation associated with damage. The equation of motion is therefore

$$\ddot{x} + (c/m)\dot{x} + \Omega^2 x = u(t)x,$$

where x is a displacement, t is time, $\Omega^2 \equiv k_{ave}/m$, and $u(t) \equiv [k_{periodic}(t) + k_{perturb}(t)]/m$. Note that $u(t)$ is proportional to the total of time-varying components of stiffness. By defining state variables $x_1 \equiv \dot{x}$ and $x_2 \equiv x$, one can divide the equation of motion into two equations in state-variable form:

$$\dot{x}_1 = -(c/m)x_1 - \Omega^2 x_2 + u(t)x^2 \text{ and}$$
$$\dot{x}_2 = x_1.$$

Suppose that vibration measurements $\tilde{x}_2(t)$ corresponding to the modeled state variable $x_2(t)$ are acquired during the interval $[t_0,t_f]$. The problem is to find the function $u(t)$ that makes the model output $x_2(t)$ approximate the measurement data $\tilde{x}_2(t)$. The problem is solved by following an optimal-tracking approach: The objective in this approach is to minimize a quadratic cost functional that (1) penalizes the deviation of $x_2(t)$ from throughout the interval $[t_0,t_f]$, (2) imposes an additional penalty on the deviation of $x_2(t_f)$ from $\tilde{x}_2(t_f)$, and (3) penalizes too large an estimate of $u(t)$ throughout the interval $[t_0,t_f]$. In the optimal-tracking formulation, the state-variable equations of motion are treated as equality constraints imposed on the minimization of cost



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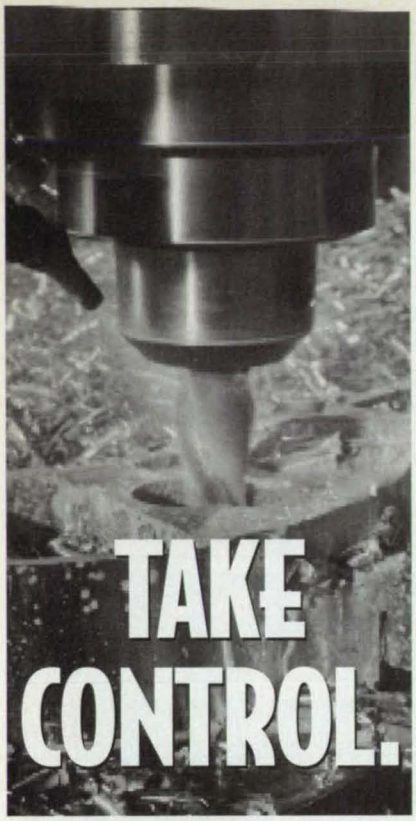

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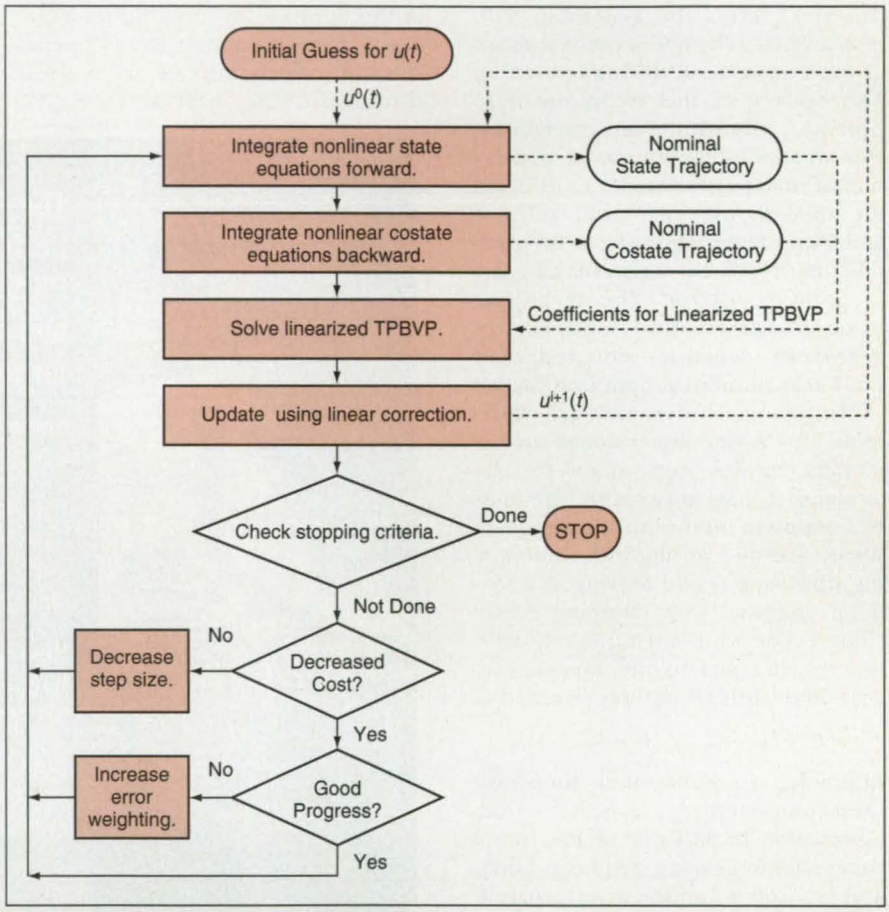
and as such they are appended to the cost function by use of time-varying Lagrange multipliers, which are governed by differential equations called the "costate equations." The state-variable equations of motion and the costate equations, taken together with a stationarity condition and end-point conditions, constitute the system of equations of a two-point boundary-value problem (TPBVP). The equations are solved numerically in an iterative procedure illustrated schematically in the figure.



The **Optimal-Tracking Problem Is Solved Numerically** in an iterative procedure. The objective is to find an approximation for $u(t)$ that minimizes a cost functional.

The technique was tested on a set of fictitious data generated by a computer simulation of a one-degree-of-freedom mechanical system with time-varying stiffness. The solution of the optimal-tracking problem was found to closely approximate the stiffness profile used in the simulation. In another test, the technique was applied to experimental data from a gear-test rig. Despite the simplicity of the one-dimensional dynamical model, the technique was found to be useful in that changes in the estimated stiffness profile could be correlated with damage.

This technique has further enhanced vibration analysis of the gear transmission done by a previously developed time-frequency Wigner-Ville distribution technique, which gives indications of the type and location, but not the extent of the damage. The two techniques are used together to monitor for the onset of damage during operation of gear trains, or to diagnose gear trains during maintenance.

This work was done by R. C. Hendricks of **Lewis Research Center** *and F. K. Choy, R. J. Veillette, V. Polyshchuk, and M. J. Braun of the University of Akron. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery and Automation category,* ***or circle no. 143*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7–3, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16454.

Printed-Circuit Board for Driving Multiple Actuators

Short-circuiting of one actuator does not cause the others to lose power.

NASA's Jet Propulsion Laboratory, Pasadena, California

A special-purpose printed-circuit board (PCB) holds power-conversion, digital control, and power driver circuits for driving as many as 20 actuators. The actuators can be electromechanical devices (e.g., relay switches or solenoid valves) that present inductive loads to their driver circuits.

Included on the PCB is a switching dc-to-dc power converter rated at a power level of 75 W. The power converter takes its input power from an unregulated source at a potential up to 36 V. The power converter generates output power for the actuators, regulated at 25 V. The regulated output voltage can be changed to any desired value within the capability of the converter by changing a single resistor on the PCB. The power converter includes a circuit for protection against undervoltage in the output load.

The digital control circuitry accepts digital control inputs for the actuators. Power is applied to the actuators through high-power, fast-switching actuator-driver circuits. There are 20 such driver circuits — one for each actuator. The driver circuitry includes twelve pairs of diodes that help to suppress inductive transients in the actuators.

The power converter can withstand a momentary short circuit in its output load. A short circuit in any actuator is detected by the undervoltage-protection circuit in the power converter. Upon sensing a low voltage indicative of a short circuit, the undervoltage-protection circuit generates an input "reset" logic signal that countermands the input digital signal for the short-circuited actuator; this causes the driver circuit for the short-circuited actuator to be disabled, while the driver circuits for the remaining actuators continue to operate normally in response to their respective digital inputs.

This work was done by Thieu T. Ton and Edward H. Kopf of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Circuits category,* ***or circle no. 144*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

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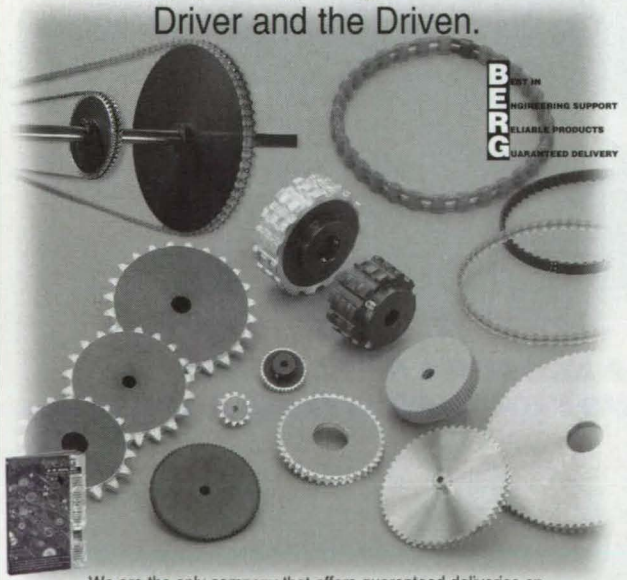

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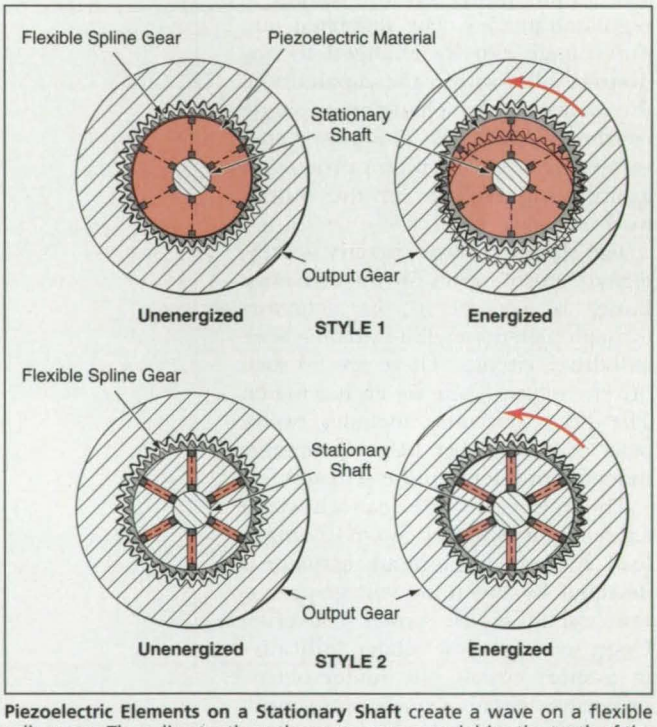
Traveling-Wave Rotary Actuators

Piezoelectrically generated traveling waves drive harmonic gears.

NASA's Jet Propulsion Laboratory, Pasadena, California

Two experimental rotary actuators combine the light weight, small volume, and cleanliness of a piezoelectric traveling-wave motor with the positive action and high torque of a harmonic gear motor. The actuators contain piezoelectric inserts that drive flexible spline gears in sinusoidal patterns; the spline gears, in turn, drive internal spur gears.

A conventional piezoelectric traveling-wave motor relies on friction between a driving flexing stator and a driven member. Friction gives rise to elements of uncertainty and slippage. A conventional harmonic gear includes a flexible gear driven by an electromagnetic motor; it produces a large, dependable torque, but the motor and gear are large, complex, and often dirty.



Piezoelectric Elements on a Stationary Shaft create a wave on a flexible spline gear. The spline teeth on the wave engage and drive the teeth of the internal spur gear.

The figure illustrates the two experimental rotary actuators. In each actuator, piezoelectric elements attached to a stationary shaft alternately bend a spline gear to larger and smaller radii at several points around the circumference. The piezoelectric elements are activated in sequence so that the teeth on the spline rise and fall in a sinusoidal wave that travels circumferentially. The teeth at the crest of the wave engage an internal spur gear (the output gear) and thus turn the gear as the crest travels around the circumference.

This work was done by Virginia G. Ford and John Kievit of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery and Automation category,* ***or circle no. 145*** *on the TSP Order card in this issue to receive a copy by mail ($5 charge).*

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For More Information Circle No. 671

Motion Control for Laser Soldering

A spreadsheet generates motion control data for a laser soldering process which is verified by computer animation.

AlliedSignal Federal Manufacturing & Technologies, Kansas City, Missouri

A method was developed to allow a user to easily generate and verify the required motion of a radar housing under a laser for a laser soldering process. The purpose of this process is to solder a lid to a backing plate in order to seal the hybrid microelectronic circuit assembly against the environment. The design of this housing makes this a nonstandard application in which a two dimensional table and

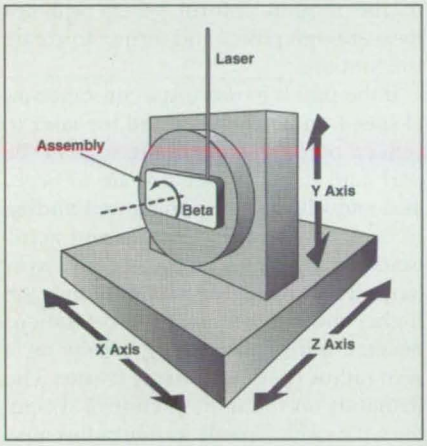
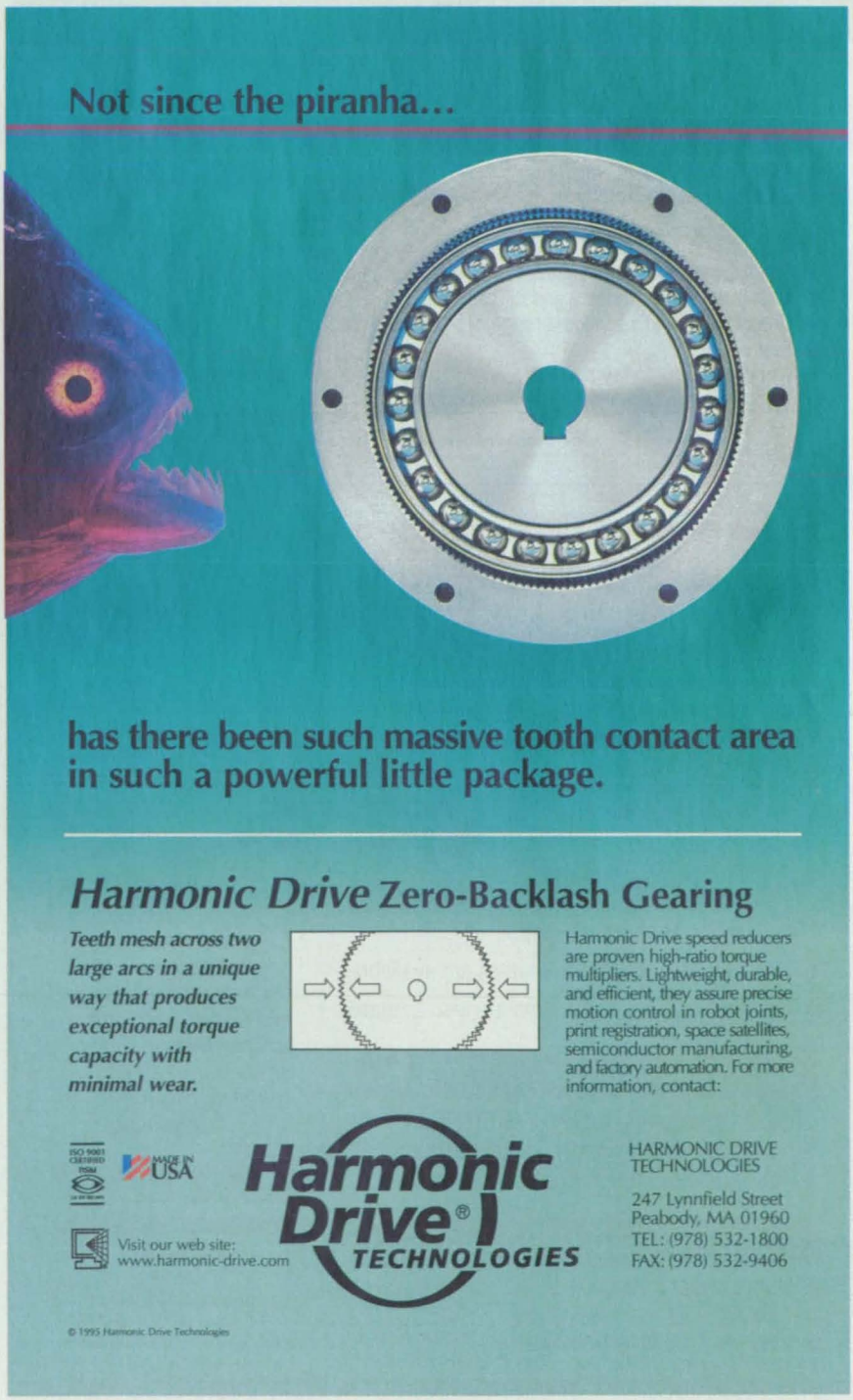


Figure 1. **Motion Control System.**

common contouring motion control operation cannot be used, because the laser is not along the axis of rotation of the part. Instead, the laser is along one of the translational axes, and the motion requires a method of driving the assembly under the laser in two dimensions while rotating about the assembly's center. To further complicate matters, there are coaxial cables which get in the way and shade the assembly from the laser beam. This requires special movements to solder under the cables.

To generate the motion, a four axis system driven by a Compumotor AT6400 indexer was used. The software to program this indexer allows for a timed data streaming mode for non-standard movements. In this mode, the user picks a streaming update interval, which may be any even number time interval from 10 milliseconds minimum to 50 milliseconds maximum. The user then supplies incremental move distances for each axis at each update point in time. In order to generate the data required for this streaming mode, a Microsoft Excel 5.0 spreadsheet was created to allow the user to easily calculate the movement of the part under the laser, and convert this movement into the incremental step moves required.

The approach to generating the data for the motion control system was to allow the user to describe the desired motion around the part in the body fixed coordinate frame. This data was then to be transformed into incremental moves in the global coordinate frame required by the motion control system. The motion around the part is defined by the user in terms of the body fixed $\mathbf{S}'$ vector. The components of this vector are the distances from the center of the part to the focal point of the laser, as the laser moves around the entire perimeter of the part. The focal point of the laser will always be on the outer surface of the part. A transformation matrix is used to convert the $\mathbf{S}'$ vector in the body fixed coordinate frame to the $\mathbf{S}$ vector in global coordinates. The position of the focal point of the laser is labeled as the $\mathbf{r}_p$ vec-



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tor and is fixed at all times with respect to the global coordinate system. The position of the center of the part (at any point in time, in global coordinates) is labeled as the $\mathbf{r}_A$ vector. This vector is found by subtracting the **S** vector from the $\mathbf{r}_p$ vector. The incremental moves used to drive the motion control system are equal to the changes in the global x and y components of the $\mathbf{r}_A$ vector. Derivatives of the **S** vector were taken to determine the velocity and acceleration of the motion control system. If the velocities are too high, whipping of the lead screw will occur. If the accelerations are too high, the stepper or servo motors of the motion control system will not have enough power and torque to create the motion.

If the part is to move at a constant travel speed under the laser and the laser to remain perpendicular to the edge of the part, and the part rotations are to begin and end with the beginning and ending of each corner, the velocities and accelerations in the corners become very large. The smaller the corner radius, the higher these velocities and accelerations become until approaching infinity for a zero radius (perfectly sharp) corner. The demands on the motion control system, for a part with a small corner radius, may be significantly reduced if the constraint of holding the part perpendicular to the laser is relaxed when nearing and exiting a corner. This allows the rotation of the part to be spread over a greater distance (beginning rotation at a small distance before reaching the corner radius, and ending rotation at a small distance after the corner radius).

A method was developed to allow the laser to solder under the area shaded by a cable. In this method, the laser is brought up to the edge of the cable diameter, or the diameter of a tolerance "keep out" zone around the cable. The edge of the laser then "hugs" this diameter as the part is rotated, to allow the beam to move under the cable. Since the angle beta is used to describe the absolute rotation of the part, the angle alpha is used to describe the angle of the laser as it moves under the cable. The angle alpha was solved using trigonometric relationships as a function of the distance of the centerline of the laser under the cable. The absolute rotation beta of the part is then either increased or decreased by the alpha angle, depending on the direction of movement around the part.

The spreadsheet and macros only require the user to provide the minimum data needed to define the desired motion of the part under the laser. This definition data consists of the major points around the part geometry where

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an event is to occur. Examples of the points which the user defines are: the starting and ending points, the corners, the cables, and any other points in which a specific travel speed under the laser or part rotation angle is desired. To make this definition easier for the user, the method for defining the moves through corners and under cables was simplified. The user simply makes a notation designating the corner number to

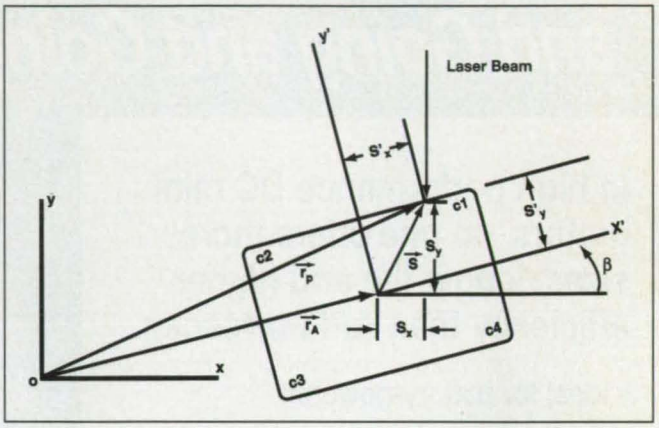


Figure 2. **Positional Vectors of Part** in body's fixed and global coordinate frames.

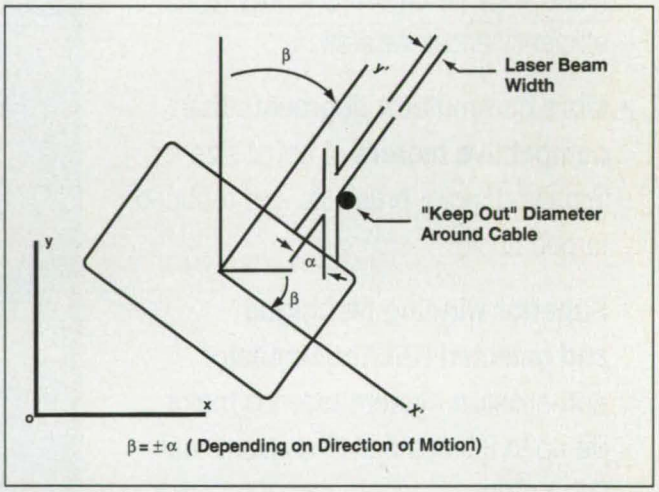


Figure 3. **Method of Rotating Part** to allow the laser to solder under cable.

define a corner move. Likewise, the user provides the minimum data required to define a cable move. The spreadsheet then generates the large amount of data that defines each incremental move at every time step that occurs between any pair of major points that the user defined.

A verification method was developed by simulating the motion data. The geometry of the assembly was generated using Parametric Technology Corporation Pro/E version 15. This geometry was then converted using DADS/Pro version 3.1 from Computer Aided Design Software Inc. (CADSI) and the simulation was carried out using DADS version 8.0 from Computer Aided Design Software Inc. (CADSI). This process animated the results of the motion of the part on the computer screen. This was extremely useful in catching and correcting errors in the Excel spreadsheet.

This work was done by Scott Yerganian of **AlliedSignal Federal Manufacturing & Technologies**. *AlliedSignal Federal Manufacturing & Technologies is operated for the United States Department of Energy under contract no. DE-ACO4-76-DP00613.*

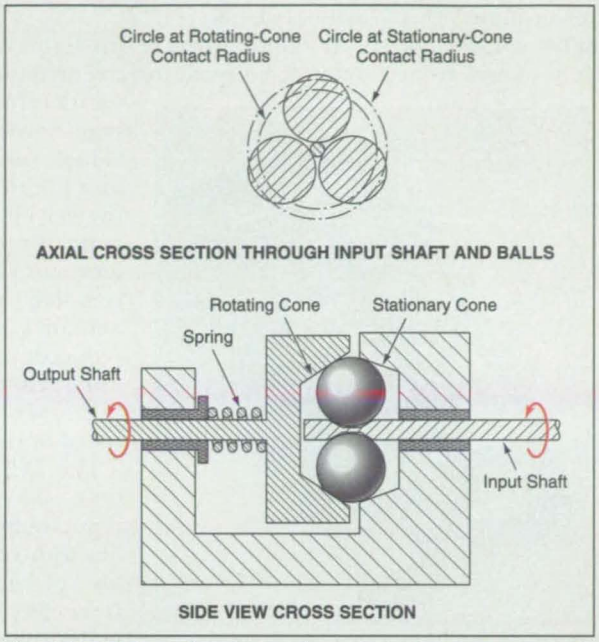
For further information contact Alan Updike at AlliedSignal FM&T, 2000 East 95th St., Kansas City MO 64131-3095; (816) 997-2605; aupdike @ kcp.com.

Planetary Speed Reducer With Balls Instead of Gears

The basic design can be adapted to numerous applications.

NASA's Jet Propulsion Laboratory, Pasadena, California

A novel friction-drive speed-reducing mechanism weighs less and occupies less space than does conventional gearing. This speed reducer can be manufactured readily with loose dimensional tolerances, does not have to be lubricated, and can function even when contaminated with dust. The basic design gives a reduction ratio of about 150 to 1 and can be readily modified to obtain other reduction ratios. The basic design can also be miniaturized and adapted to a variety of applications that could include miniature robots, small instruments, and toys.



The **Balls and Cones** function analogously to planet gears and ring gears. The speed-reduction ratio depends on the ratio between the radii of contact of the two cones with the balls.

This speed reducer (see figure) has a differential planetary configuration, but with balls instead of planet gears and cones instead of ring gears. A spring presses the balls between two cones, one of which is stationary, the other of which can rotate and is connected to an output shaft. The conical tapers are chosen to make the radius of contact between the stationary cone and the balls slightly greater than the corresponding radius for the rotating cone. Rotation of an input shaft causes the balls to rotate in planetary fashion. The small difference between the radii of contact produces a differential rotation that is coupled to the output shaft.

This work was done by Donald B. Bickler of Caltech for **NASA's Jet Propulsion Laboratory**. *No further documentation is available.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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For More Information Circle No. 695

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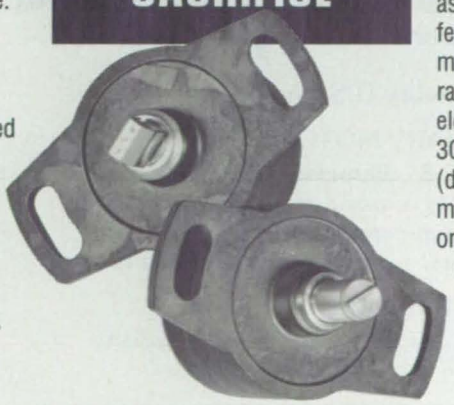

SP 2800s are also impervious to dust and moisture by sealing to the IP 65 standard. Reliability is further enhanced by utilizing a precious metal, multi-finger wiper assembly. Other features include mechanical travel range of 360°, electrical travel of 308° or 100° (depending on model), and push-on coupling or marked shaft provide easy mounting options.

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For More Information Circle No. 677

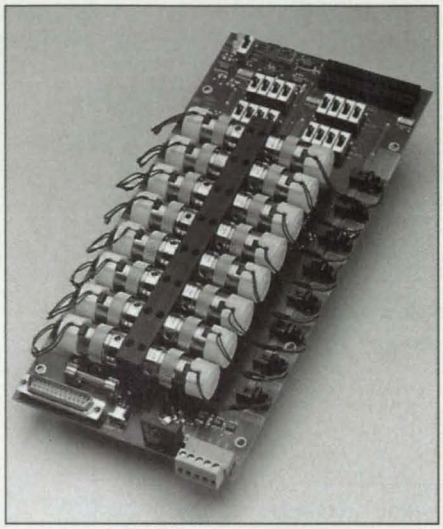
An Interface for Electro-Pneumatic Communications

A bidirectional serial interface communicates at speeds up to 500 kbaud in the control of pneumatic valving.

Clippard Instrument Laboratory, Inc., Cincinnati, Ohio

Today's market requires machines with increased throughput, extremely low down time, and ability to combine multiple operations with minimal human input. This results in machines requiring highly complex control systems to move large amounts of data rapidly to and from operating members. Yet, in the face of global competition, the pressure is on for extreme reliability in data communication at reduced cost. As a result, Clippard has developed a highly reliable bidirectional serial communication interface. Termed the Serial Valve Board (SVB), it operates according to the DeviceNet™ protocol, the open communication system for industrial devices developed by Allen Bradley and now overseen by the Open DeviceNet™ Vendors Association.

The SVB is a node used to interface between a control entity or entities and a pneumatic valve manifold. The SVB accepts commands from the control and returns status. In addition, the SVB can be used to interface to electronic sensors transmitting digital input to the controller. The serial data is carried over a four-conductor cable that is connected to each node in trunk-line, drop-line configuration, in which drops can be daisy-chained.



The **Serial Valve Board** (SVB) shown with manifolded valves mounted on it.

A unique aspect of this device is that the SVB can be either mounted directly to a solenoid valve manifold or in a central location for a limited group of valves that are wired to the interface by individual connectors. This allows the user to run a single bus cable through the machine, connecting to each SVB node. By using the SVB at specific locations within a device connected to remotely mounted solenoids, the amount of wiring is significantly reduced. At the same time, the valves can be closely coupled to their respective operators, thereby enhancing speed of response.

The SVB, in its current configuration, can connect either 8 or 16 input/outputs (I/O) to a DeviceNet™ bus with custom configurations capable of up to 64 I/O. Since a DeviceNet™ bus can have up to 63 nodes (plus one for a controller), this device provides the flexibility to connect hundreds or even thousands of I/O via a limited number of connections. Data transmission speeds up to 500 kbaud are possible, depending on total bus length. Applications for this technology include conveyor and sorting lines, automated inventory pull systems, and multimachine manufacturing cells, among others.

Power to the SVB is provided by the bus cable for low-power applications; otherwise, a power-input connector is provided. On-board short-proof drivers actuate the solenoids, Zener diodes provide fast turn-off and coil spike suppression, and a regulator produces 5 V (required internally by the board) from the 24-VDC input. These protection features make optoisolators unnecessary.

Solenoids can draw up to 700 mA each and are operated independently. The SVB has a maximum switching frequency of 100 Hz per solenoid. The drivers will drop a maximum of 0.6 V at 700 mA.

The SVB allows the bus address (MAC ID) to be set manually. Since the DeviceNet™ protocol allows bus addresses from 00 to 63, any setting higher than 63 will place the SVB in automatic self-test cycle, wherein each contact is tested for open or shorted coils. All valves are off at power-up, and the self-test is performed before the SVB is allowed to go online. Any fault detected is reported to the controller. In addition, each contact has an on-board LED that will flash if a fault is detected.

To facilitate installation and field service, manual override switches for each contact are provided. These switches are three-position slides, allowing the contact to be manually off, manually on, or under the aegis of the controller(s).

This work was done by a team, with Sid Hendry as Project Manager, at **Clippard Instrument Laboratory**, *7390 Colerain Rd., Cincinnati, OH 45239. For more information call Sid Hendry at (513) 521-4261 or E-mail: shendry@ix.netcom.com.*

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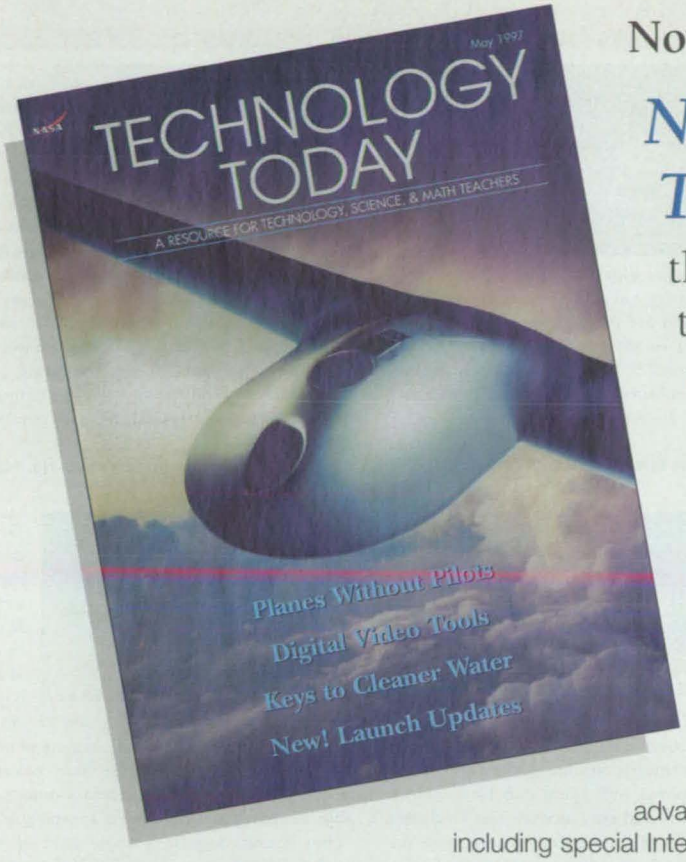

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Firestone Industrial Products Co., Carmel, IN, says the 2M2A **air actuator**, dubbed the Microactuator, is the smallest air spring offered by the company and the smallest available from any manufacturer. A pneumatic bellows-type air cylinder, it can utilize pressures from 0 to 100 psi; at 100 psi it can lift 200 lb. Maximum diameter is 2.2 in. Because the 2M2A's minimum height is 1.2 in., it is suited for small-space applications, yet can deliver more than 1 in. of stroke.

For More Information Circle No. 747

Haydon Switch and Instrument (HSI), Waterbury, CT, has expanded its product line to include **gearmotors** that incorporate the company's stepper motors with a rugged cast metal gearbox. The gearboxes can sustain loads up to 200 oz.-in. of torque and are available in a range of gear ratios from 12:1 to 360:1. The stepper motors are built with 15° or 7.5° step angles. Gears are constructed of composites, brass, hardened steel or a combination of these materials.

For More Information Circle No. 748

Motion Engineering Inc. (MEI), Santa Barbara, CA, calls its CPCI/DSP the first **8-axis level motion controller** for the Compact/PCI bus. The device provides up to 8 axes of servo or stepper control in a single 6U Compact/PCI bus card. It offers point-to-point and coordinated motion, electronic gearing and camming, dual-loop control, and a variety of motion profiles, including trapezoidal, S-curve, parabolic, and user-defined.

For More Information Circle No. 749

The 25M Series, the newest family of **AC flux vector controls** from Baldor Electric Co., Fort Smith, AR, has a NEMA 4x keypad with a 32-character English-language display for drive setup. One power supply module powers several 25M controls, which in turn drive several AC vector motors. Control range is from 2-90 A continuous, and input is either direct 230 or 460 VAC. Baldor says its auto-tuning system reduces setup time.

For More Information Circle No. 750

Ruland Manufacturing Co., Watertown, MA, has expanded its NOMAR® line of **rigid shaft couplings** and added **beam-style flexible couplings** to its line. The rigid line now includes couplings with bores from 1/4 in. to 2 in. They come in 1- and 2-piece clamp-style designs, and are available in carbon steel, stainless steel, and aluminum. The beam-style flexible devices are 1-piece aluminum couplings with spiral cuts to accommodate misalignment and axial motion. The Flexbeam-3™, with two sets of three spiral cuts for high torsional strength, is designed for use on servo motors, encoders, tachometers, and similar components.

For More Information Circle No. 751

The new A-max **moving coil motors** from Maxon Precision Motors, Burlingame, CA, are just 31.9 mm long and 22 mm in diameter. Available with either precious-metal brushes or graphite brushes, the motors have power ratings from 3.5 to 6 W. Several different windings are available to match desired speed to available voltage. Other options include a single shaft or a passing shaft, ball bearings or sleeve bearings, and terminals or leads.

For More Information Circle No. 752

The Series ML **multimotion actuators** from PHD Inc., Fort Wayne, IN, are designed to provide both linear and rotary motion in one compact unit. The series uses PHD's Series CTS compact guide rod cylinder and Series RL rotary actuator to achieve simple reach-and-turn motion. They are available in 7 sizes with six standard rotations from 45-270° and linear stroke lengths from 1/8 in. to 3 1/2 in. Shock pads, standard on the linear section and optional on the rotary section, minimize piston noise and extend unit life, PHD says.

For More Information Circle No. 753

Eastern Air Devices, Dover, NH, describes its new DB23 and DB34 **brushless DC servo motors** as being designed for high-speed processing applications where precision accuracy is important. Their 3-phase design is compatible with industry-standard servo amplifiers and controllers. Equipped with rare-earth magnets, the motors operate at speeds up to 15,000 rpm. Optical encoders provide 500- or 1000-line precision position feedback for standard servo controllers.

For More Information Circle No. 754

Vickers Inc., Maumee, OH, introduces the KB Series **proportional directional valves** that the company says combine advanced electrohydraulics technology with "plug and play" integrated electronics in a compact package. Available in ISO sizes 03 and 05, the valves are rated at 350 bar (5000 psi), and can be placed directly on the cylinder or motor regardless of environment. Fluid cleanliness levels are ISO 18/16/13, a more lenient fluid contamination level than conventional proportional valves, Vickers says.

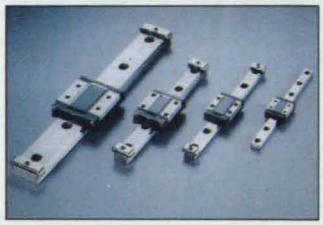
For More Information Circle No. 755

The new DSL series of **pneumatic actuators** from Festo Corp., Hauppauge, NY, features rotary, linear, and simultaneous rotary/linear actuation in one compact module. The series comes in 4 metric bore sizes: 16, 20, 25, and 32 mm, with double-ended or hollow double-ended piston rod options. The actuation combination is made possible by a double-acting vane-type rotary actuator for adjustable rotation angles up to 270° and a double-acting linear pneumatic cylinder with linear strokes up to 4 in.

For More Information Circle No. 758

Micro Mo Electronics, Clearwater, FL, has introduced the MVP™ 2001 **single-axis motion controller.** The only controller to date to be certified as DeviceNet™ compliant, according to the company, the MVP can provide control of motion, velocity, and position via serial or DeviceNet interfaces with a wide range of brush-type and brushless DC motors. Up to 63 motor axes can be addressed using the RS-485 Multidrop interface. It is offered in two versions: with either an integrated PWM amplifier or an integrated linear amplifier.

For More Information Circle No. 759



The Type RSR-Z **linear motion guide** from THK America, Mount Prospect, IL, features the use of resin in the block body, decreasing the block's mass by up to 28 percent compared to the conventional Type RSR-V. Areas of passage free of loads applied by the ball bearings are molded in resin, resulting in silent operation. The stainless-steel construction of the miniature guide gives it corrosion resistance.

For More Information Circle No. 760

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Books & Reports

Factors That Affect Readings of Ultrasonic Bolt-Load Gauges

Three reports discuss the principles of operation and factors that affect the readings of ultrasonic extensometers used to measure preloads in bolts, studs, and similar fasteners. These instruments measure "ultrasonic lengths" proportional to round-trip times of travel of ultrasonic pulses along fasteners. To a first approximation, the amount by which the ultrasonic length of a fastener under tensile load differs from the unloaded length is proportional to the load, and can thus be used to indicate the load. However, the reading of the ultrasonic instrument is complicated by such other effects as thermal expansion of the fastener, dependence of the speed of sound on temperature and stress, and variations in tension along the gripped portion(s) of the length of fastener.

This work was done by Ajay M. Koshti of Rockwell International Corp. for **Johnson Space Center**. *To obtain copies of the reports, "Estimation of Accuracy in Ultrasonic Preload Measurements," "Preload Measurement in Sleeve Bolts Using An Ultrasonic Bolt Gage," and "Preload measurement in sleeve bolts using an ultrasonic technique," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category,* ***or circle no. 136*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*
MSC-22674

Adaptive Footpads With Pyrotechnically Anchored Tethers

A report describes a proposed system for landing a spacecraft on a comet, asteroid, small planet, or other extraterrestrial body with low gravitation. The system would include three terrain-conforming footpads rigid enough to withstand impact on a hard surface and broad enough to land on a soft surface without sinking excessively. Each footpad would be equipped with sensors, a pyrotechnically actuated harpoon, and a winch connected to the harpoon via a tether. In computational simulations, the system has been found to be capable of arresting rebound and rollover during landings on terrains with a variety of slopes and obstacles.

This work was done by Randel Lindemann, Donald Sevilla, Kevin Burke, and Greg Gillis-Smith of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Adaptive Footpad With a Pyrotechnically Anchored Tether for Landing Gear on Low Gravity Planetary Bodies," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery and Automation category,* ***or circle no. 147*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*
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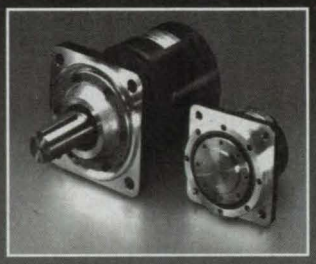

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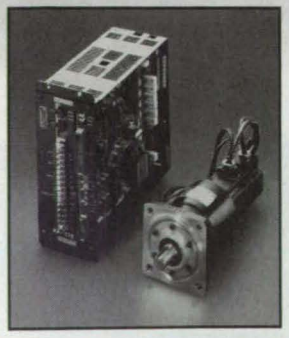

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For More Information Circle No. 451

High-Temperature Fatigue Testing of PMCs

A report describes an experimental study of the tensile and cyclic fatigue behavior of a polyimide-matrix/carbon-fiber composite material under elevated-temperature conditions. The study was undertaken primarily to develop and refine techniques of high-temperature, uniaxial (tension/compression) fatigue testing of polymer-matrix composite (PMC) materials in general.

This work was done by John R. Ellis of **Lewis Research Center**, *Andrew L. Gyekenyesi of Cleveland State University, and Michael G. Castelli and Christopher S. Burke of NYMA, Inc. To obtain a copy of the report, "A Study of Elevated Temperature Testing Techniques for the Fatigue Behavior of PMCS: Application to T650-35/AMB21," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category,* ***or circle no. 128*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7–3, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16496.

More About a Laser-Speckle Surface-Strain Gauge

The report, "Compact Simultaneous-Beam Optical Strain Measurement System — Phase V," is one in a series of documents about an optoelectronic instrument that uses laser speckle for noncontact measurement of strains on the surfaces of specimens, which can be hot even though the instrument remains at room temperature. Several prior articles in *NASA Tech Briefs* have described this instrument at various stages of development; the most recent description appeared in "Improvements in a Laser-Speckle Surface-Strain Gauge" (LEW-15914), Vol. 20, No. 4 (April 1996), page 54. The report reiterates information from the prior articles and supporting documents and describes some more-recent advances. One notable advance addresses a disadvantageous reduction in the separation of speckle patterns that are generated by two lasers and imaged in a video camera. Such a reduction occurs during observation of a depolarizing specimen. The report proposes the use of two different laser wavelengths, combined with the use of a refracting prism in front of the camera, to increase the separation of the corresponding speckle patterns.

This work was done by Christian T. Lant of Sverdrup Technology, Inc., for **Lewis Research Center**. *To obtain a copy of the report, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category,* ***or circle no. 189*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

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Macrosegregation and Nucleation in Undercooled Pb/Sn Alloys

A report describes an experimental study of macrosegregation and nucleation in three alloys of Pb and Sn. The alloys had tin contents of 12.5, 61.9 (eutectic), and 77 weight percent. Ingots of the alloys, each with a volume of 2.7 cm^3, were melted, then frozen with undercoolings ranging from 4 to 34 K and cooling rates from 0.04 to 4K/s. The nucleation behavior of the Pb/Sn system was found to be nonreciprocal; the solid Sn phase effectively nucleated the Pb phase of the eutectic, but large undercoolings developed in Sn-rich eutectic liquid in the presence of the solid Pb phase. This phenomenon is believed to be mainly a result of differences between interfacial energies of (1) solid Sn/eutectic liquid and (2) solid Pb/eutectic liquid. Amounts of macrosegregation in eutectic ingots were found to increase with undercooling.

This work was done by Henry C. deGroh III of **Lewis Research Center**. *To obtain a copy of the report, "Macrosegregation and Nucleation in Undercooled Pb-Sn Alloys," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category,* ***or circle no. 149*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*

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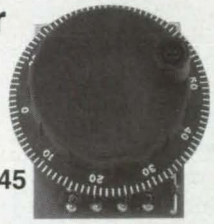

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For More Information Circle No. 440

Reconfigurable Pointing Control for Spaceborne High-Resolution Spectroscopic Instruments

A collection of documents summarizes preliminary efforts to develop improved pointing control for spaceborne scientific instruments. A significant effort was expended to develop a theory to provide a pointing-control-performance criterion, the satisfaction of which would ensure the acquisition of high-quality data by high-resolution spectroscopic instruments. The theory is presented and it is found that the criterion is very stringent and difficult to satisfy by use of standard three-axis spacecraft control equipment now in use. This finding leads to the second major effort, regarding a novel reconfigurable-control concept proposed to satisfy the pointing criterion while using currently available gyroscopic spacecraft hardware. This concept involves switching the control error (which one seeks to null) among detuned Kalman filters. The feasibility of the concept is verified by use of a covariance analysis, and effectiveness is demonstrated by example calculations for the Infrared Spectrograph (IRS) payload aboard the Space Infrared Telescope Facility (SIRTF). Numerical results indicate that by proper choice of filter detuning and handoff timing, the optical flux offset could be held (with 0.95 probability) to within 6 percent of the ideal flux. In contrast, the corresponding flux offset would be 12 percent with conventional three-axis control.

This work was done by David S. Bayard, Tooraj Kia, and Jeff Van Cleve of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the collection, "Reconfigurable Pointing Control for High Resolution Space Spectroscopy," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Systems category,* ***or circle no. 140*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*
NPO-20182

Using Genetic Algorithms To Plan a Spacecraft Landing

A report summarizes a study in robust flightpath planning for a low-lift spacecraft to land on Mars. The basic problem was one of optimization: to plan a sequence of control actions — specifically, shifts in the position of an internal proof mass to change the center of mass of the spacecraft and thereby shift its angle of attack — to make the final landing position as insensitive as possible to such perturbations as errors and uncertainties in approach-trajectory parameters and in mathematical modeling of the Martian atmosphere. In the study, landing trajectories were computed by a nonlinear mathematical model of the descent dynamics, and optimization was performed by use of genetic algorithms to minimize a quadratic cost function of the landing miss distance over several realistically perturbed trajectories. It was found that by suitable scheduling of proof-mass shifts, the perturbed trajectories could be made to coalesce to a "bounce and drop" form, with root-mean-square landing errors reduced from 111 to 43 km. The results of this study also indicate that while genetic algorithms require long processing times (200 hours in this case), they are fairly easy to program and can provide useful solutions to complex optimization problems.

This work was done by David S. Bayard and Hamid Kohen of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Robust Flight Path Determination for Mars Precision Landing Using Genetic Algorithms," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category,* ***or circle no. 160*** *on the TSP Order Card in this issue to receive a copy by mail ($5 charge).*
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API Controls Inc.

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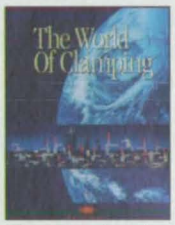

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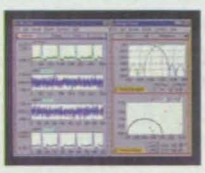

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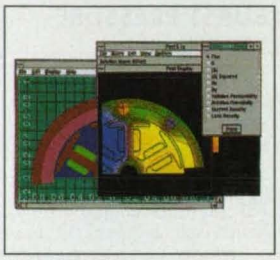

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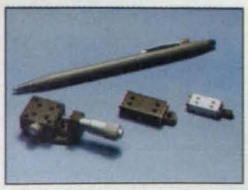

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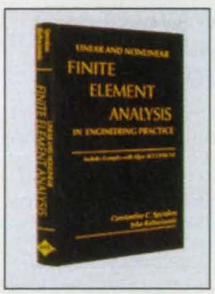

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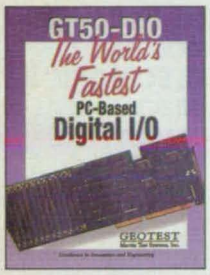

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For More Information Circle No. 627

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Bulb Direct, Inc. sells replacement specialty lamps for A/V, photographic, stage, studio, video, micrographic, and graphic arts equipment, plus medical and electronic instruments. We offer brand names with two-day air delivery at no extra cost! New this year...Specialty Energizer Batteries. Bulb Direct Inc., 1 Fishers Rd., Pittsford, NY 14534-9511; Tel: 800-772-5267 or 716-385-3540; Fax: 716-385-4976.

Bulb Direct, Inc.

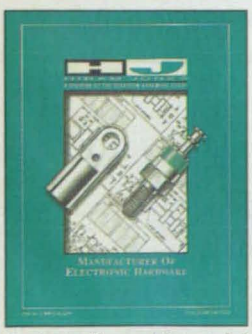
For More Information Circle No. 628

VESPEL® POLYIMIDE PARTS & SHAPES

DuPont Vespel® parts offer reliability and durability for semiconductor manufacturing. These high-performance components can reduce costs through longer life and extended maintenance intervals versus quartz and ceramics. Vespel® parts perform at high temperatures, resist chemical attack, and exhibit superior cleanliness, dimensional stability, and dielectric performance. Applications include clamping rings and other "in chamber" applications, wafer handling and processing, and IC handling and testing. DuPont Engineering Polymers, Barley Mill Plaza, Bldg. 22, PO Box 80022, Wilmington, DE 19880-0022; Tel: 800-972-7252.

DuPont Engineering Polymers

For More Information Circle No. 629



Hiram Jones Electronics, Inc./A Division of the Seastrom Hardware Group manufactures a complete line of standard miniature and subminiature terminals including: insulated test jacks, assembled standoffs and press-type terminals. All standard catalog items are available for immediate pricing and delivery. Call today for your free 27-page catalog: 800-634-2356.

Hiram Jones Electronics, Inc.

For More Information Circle No. 630

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Tel: 630-851-1734 Fax: 630-851-2106

For More Information Circle No. 631

COMPUTERS AND ELECTRONICS

Circuit Specialists, Inc., in business for 26 years. Our 150-page catalog has over 9,000 products including industrial & personal computers, computer peripherals, board-level data acquisition & control products, test equipment, motion control products, educational laser & fiber optics, wiring products & much more. Circuit Specialists, Inc., 220 S. Country Club Dr., Bldg. 2, Mesa, AZ 85210; 24-hour catalog request line: 800-811-5201, ext. 5; Fax: 602-464-5824; http://www.cir.com

Circuit Specialists, Inc.

For More Information Circle No. 632

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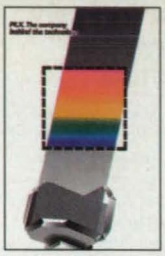
For More Information Circle No. 633



PLX HOLLOW RETROREFLECTOR BROCHURE

Pioneers in the development of hollow retroreflector technology, PLX can provide solutions where great optical stability and high-quality wave fronts are essential. The brochure features products designed for a variety of military, aerospace, industrial, and medical applications involving boresighting, interferometry, and spectroscopy. For a free copy, contact Jack Lipkins at: PLX, 40 Jeffryn Blvd., Deer Park, NY 11729; Tel: 516-586-4190; Fax: 516-586-4196; E-mail: plx@netusa.net

PLX

For More Information Circle No. 634

VXI PRODUCTS

The new HP Systems Builder's Source includes comprehensive technical information for the most complete selection of test system components available. Test system and VXI components, HP VEE - the graphical programming language for test engineers - and custom system integration services are detailed for solutions in electronic manufacturing test and data acquisition applications ranging from telecommunications to automotive. For a FREE catalog and CD-ROM, call Hewlett-Packard at 800-452-4844, ext. 1803.

Hewlett-Packard

For More Information Circle No. 635

1997 PCMCIA PRODUCTS CATALOG

The new PCMCIA-PC CARD standard has been incorporated into many new applications such as: Data-logging, agriculture, digital film, and wireless communications. Envoy Data has just released its new catalog for these new applications plus many other products like: memory, I/O (serial, parallel, SCSI, A/D, etc.) cards; PC card drives for ISA, IDE, SCSI, etc.; along with industrial card and drives, multimedia, industrial, and engineering tools for PCMCIA applications. Envoy Data Corporation, 6 E. Palo Verde, #3, Gilbert, AZ 85296; Tel: 602-892-0954; Fax: 602-892-0029; e-mail: info@envoydata.com; http://www.envoydata.com

Envoy Data Corporation

For More Information Circle No. 636

EMI/RFI SHIELDING PRODUCTS

New catalog details hundreds of standard gaskets and grounding strip variations, engineered to meet the most common shielding applications. Standard as well as custom designed shields are manufactured from Beryllium, Copper, and other High-performance materials. Special finishes and a variety of mounting methods are offered. For World Class quality and service call 973-890-7455 or visit our Web Site at: HTTP://WWW.OMEGASHIELDING.COM; e-mail: SALES@OMEGASHIELDING.COM

Omega Shielding Products Inc.

For More Information Circle No. 637

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For More Information Circle No. 638

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Automated Precision, Inc.

For More Information Circle No. 639

HI-TEMP SOLUTIONS WORLDWIDE

Aremco produces high-temperature ceramics, adhesives, coatings, sealants, tapes, greases, castables, and potting compounds. These materials are used throughout industry in the design of sensors, electrical components, and analytical instruments, as well as the maintenance of high-temperature industrial process equipment. Aremco also produces dicing equipment and screen printers which are used in the processing of electronic and technical ceramics. Aremco Products, Inc., PO Box 429, 23 Snowden Ave., Ossining, NY 10562-0429; Tel: 914-762-0685; Fax: 914- 762-1663.

Aremco Products, Inc.

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Ironwood Electronics

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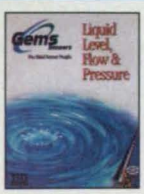
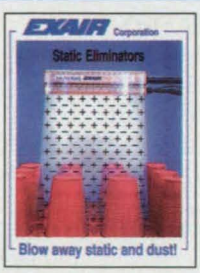


NEW LEVEL, FLOW AND PRESSURE SENSORS CATALOG

New 232-page catalog (more than 350 standard products) is now available from The Fluid Sensor People™ at GEMS! In addition to the thousands of sensor variations for OEM design engineers, the full-color Qwik Piks™ Section showcases hot products and cool tips for novices and experts alike, plus same-day shipping! Sensor technologies include: ultrasonic, electro-optic, fiber-optic, float, conductivity, Hall Effect, CVD transducers, and more. Gems Sensors, 1 Cowles Rd., Plainville, CT 06062; Tel: 800-321-6070; Fax: 860-793-4500.

Gems Sensors

For More Information Circle No. 642



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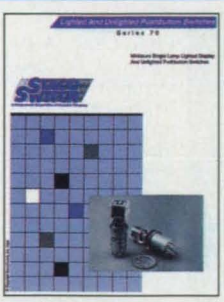
EXAIR Corporation

For More Information Circle No. 643



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StacoSwitch

For More Information Circle No. 644

POWDER METALLURGY DESIGN SOLUTIONS

This 20-page brochure, published by the Powder Metallurgy industry trade association, is yours free for the asking. It features cost-effective design solutions and new ways to handle parts fabrication. Metal Powder Industries Federation, 105 College Road East, Princeton, NJ 08540; Tel: 609-452-7700; Fax: 609-987-8523; http://www.mpif.org

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For More Information Circle No. 645

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PRECISION ALUMINUM EXTRUSIONS

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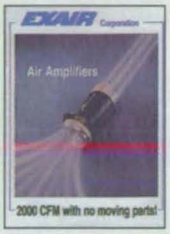
For More Information Circle No. 647

VIBRATION ISOLATION & IMPACT ABSORPTION

New, full-color brochure describes the dynamic properties of Sorbothane, the unique vibration isolation and impact absorption material. New test data details the damping properties of Sorbothane compared to other elastomers. Sorbothane is a patented visco-elastic polymer. Includes information on Sorbothane's new line of advanced vibration isolation/shock absorption products, as well as applications engineering, manufacturing capabilities, and the many applications for Sorbothane. Sorbothane, Inc.; Tel: 330-678-9444; Fax: 330-678-1303; E-mail: webmaster@www.sorbothane.com; http://www.sorbothane.com

Sorbothane, Inc.

For More Information Circle No. 648



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EXAIR Corporation

For More Information Circle No. 649

METAL BELTS AND DRIVE TAPES

This general product brochure describes the various attributes that make metal belts and drive tapes an exceptional and exciting option for design engineers. Manufactured by Belt Technologies for 25 years, this unique family of products has helped design engineers overcome challenging application requirements in the electronics, aerospace, biomedical, optical and packaging industries. Belt Technologies, Inc., PO Box 468, Agawam, MA 01001; Tel: 413-786-9922; Fax: 413-789-2786.

Belt Technologies, Inc.

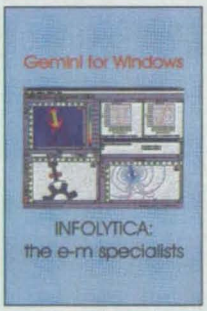
For More Information Circle No. 650

TOOLING COMPONENTS AND CLAMPS

This 500-page catalog contains an assortment of components including toggle clamps, modular fixturing, clamping devices, power workholding, chuck jaws, pins, knobs, drill bushings, leveling feet, and much more. Carr Lane Manufacturing Co., 4200 Carr Lane St., PO Box 191970, St. Louis, MO 63119-7970; Tel: 314-647-6200; Fax: 314-647-5736.

Carr Lane Manufacturing Co.

For More Information Circle No. 651



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For More Information Circle No. 652

NEW GUIDE TO SPRING DESIGN

Mid-West Spring's new Guide to Spring Design helps engineers/designers plan, design and specify springs. Brochure includes design formulae, materials property and Wahl curvature stress correction data. Compression, torsion and extension springs are discussed, along with materials data on high carbon spring steel, steel alloys, stainless steel, non-ferrous, and high temperature alloy wire and flat high-carbon spring steels. For a free copy contact Mid-West Spring Manufacturing Company, 1404 Joliet Road, Unit C, Romeoville, IL 60441; Tel: 800-619-0909; Fax: 708-739-3890.

Mid-West Spring Manufacturing Co.

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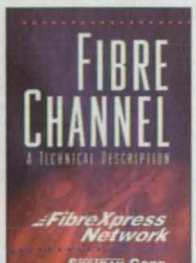

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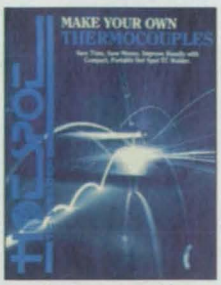

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The HOTSPOT allows thermocouple wire to be formed into free-standing junctions, or welded to metal surfaces. It provides a simple means of fabricating thermocouples "when needed and where needed." Brochure and specification sheet available. Address: 7300 North Crescent Blvd., Pennsauken, NJ 08110. Tel: 609-662-7272; Fax: 609-662-7862; http://www.thomasregister.com/dcc

DCC Corp.

For More Information Circle No. 655

INSTRUMENT DATA ACQUISITION

The SoftwareWedge™ directs serial (RS-232, RS-485, RS-422) data from any instrument into any Windows 3.x, 95, or NT application such as Excel, MMIs, VB, Control, and Statistical applications. This configurable driver provides full data acquisition and control of PLCs, data loggers, scales, flow meters, lab instruments, etc. Please contact TAL Technologies, Inc., 2027 Wallace St., Philadelphia, PA 19130; Tel: 800-722-6004 or 215-763-7900; Fax: 215-763-9711; http://www.taltech.com

TAL Technologies, Inc.

For More Information Circle No. 656

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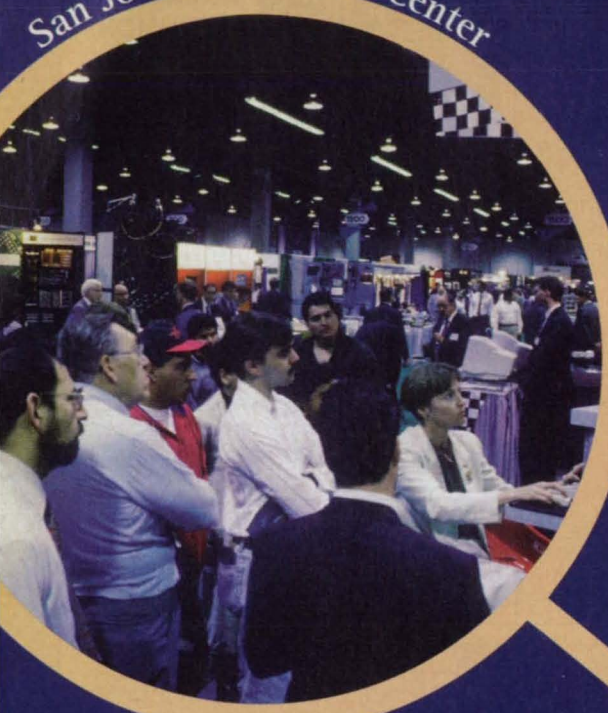

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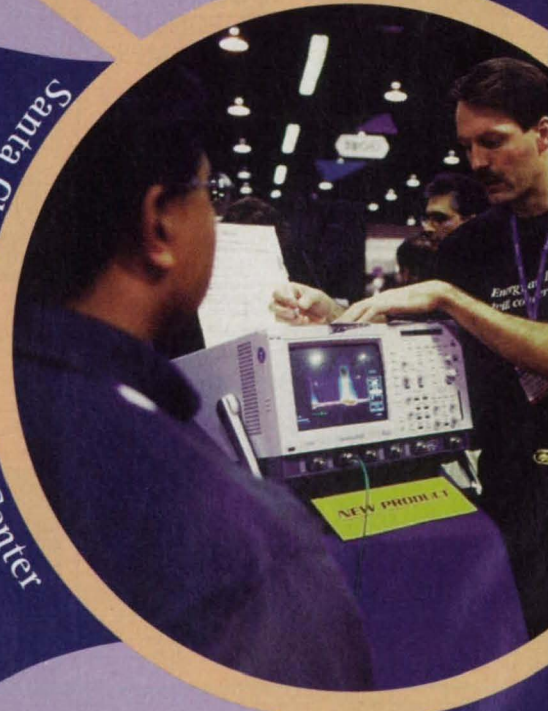

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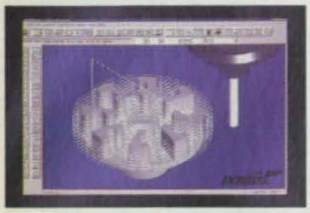
For More Information Circle No. 532

New on Disk

Product of the Month



Manufacturing and Consulting Services, Scottsdale, AZ, has announced Anvil Express™ **CADD/CAM software** for Windows that includes the SolidWorks™ solid modeler for parts and assembly modeling, multiple-surface milling, tool path simulation and verification, photo-realistic rendering and animation, and Autosnap-3-D™ technology that automatically generates solid models from 2D geometry with a single mouse click. Other features include multimedia tutorials; parametric, surface, and wireframe modeling; and NC programming with support for multiple-surface machining.

For More Information Circle No. 700

Gridgen version 12 **numerical grid generation software** from Pointwise, Bedford, TX, uses OpenGL 3D graphics. The software enables construction of meshes for use with CFD and finite-element analysis software, and includes geometry modeling, IGES import, grid generation, and compatibility with Silicon Graphics, Hewlett-Packard, and IBM workstations.

For More Information Circle No. 707

Eos Systems, Vancouver, BC, Canada, has introduced Photo-Modeler Pro 3.0 **modeling software** that creates 3D models of existing objects and scenes through the use of photographs. Features include automatic camera orientation, surface drawing, enhanced file export and photo-texturing.

For More Information Circle No. 704

B.A. Intelligence Networks, Southfield, MI, has released a new version of BAAN PDM **design-to-manufacturing software** that provides two-way transfer of product-related data through an integrated suite of document management, versioning and change control, and product structure and workflow management capabilities.

For More Information Circle No. 708

TechOptimizer 2.5 Professional Edition Windows 95/NT **engineering solution software** from Invention Machine, Boston, MA, supports engineers in the conceptual stage of product and process development. TechOptimizer Module allows engineers to correctly state a problem; Effects, Principles, and Prediction Modules help find solutions; and the Feature Transfer Module allows transfer of desirable features from one system to another.

For More Information Circle No. 705

HyperForm™ **metal stamping simulation software** from Altair Computing, Troy, MI, contains HyperMesh® finite-element pre- and post-processor, and Simex® finite-element code for sheet metal forming. The program allows users to identify and correct potential stamping problems.

For More Information Circle No. 701

AC Technology North America, Louisville, KY, has introduced C-MOLD 3D QuickFill **injection molding simulation software** that accepts solid geometry models from any CAD package, and displays simulation results on the designer's solid model. The software reveals potential design or manufacturing problems and provides solution advice.

For More Information Circle No. 702

Microcal Software, Northampton, MA, has announced Origin™ version 5.0 Windows-based **data analysis and technical graphics software** for analyzing, graphing, and presenting data. The software opens Excel workbooks within its work space, allowing users to visually manipulate data within the Origin graph.

For More Information Circle No. 706

Corel Corp., Ottawa, ON, Canada, offers CorelCAD™ Modeler **solid modeling software** for visualizing, manipulating, and refining of 3D models. Based on ACIS® solid modeling, the program allows sharing and collaboration by multiple users. The Windows 95/NT 4.0-compatible software enables creation of parts and components individually, allowing users to arrange them into a single assembly.

For More Information Circle No. 703

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For More Information Circle No. 442

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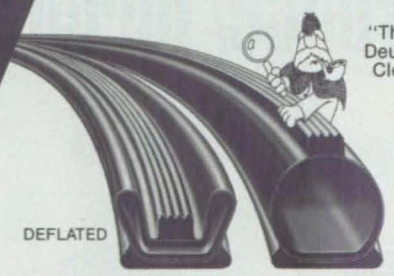

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For More Information Circle No. 444

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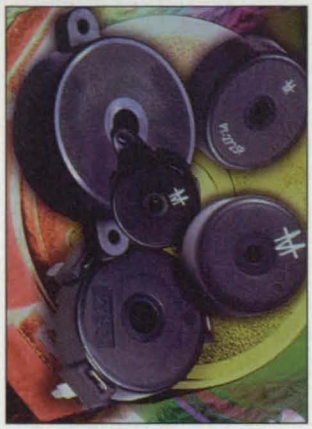
For More Information Circle No. 445

New on the Market



North American Capacitor Co., Indianapolis, IN, offers **piezoelectric and electromagnetic transducers.** The piezo transducers are available in external drive with no feedback, self-drive with feedback, surface mount, miniature speaker/piezo type, and miniature speaker cone type styles with sound output from 75 dB to 105 dB. Electromagnetic transducers are available with mounting pins or lead wires and offer sound outputs of 80 dB or 85 dB at 1.5V.

For More Information Circle No. 720

The TOObender electronically controlled, motor-driven **tube bender** from Swagelok Co., Solon, OH, bends carbon steel and stainless steel tubing in 1, 1-1/4, 1-1/2, and 2-inch sizes with a bending range from 1 to 110 degrees. The bender is self-contained and operates horizontally or vertically. Bends can be preset, and a digital display shows degree and progress of the bend.

For More Information Circle No. 714

Endura Coatings, Warren, MI, has introduced two synergistic **coatings** for use in the aerospace, automotive, chemical processing, packaging, plastics, medical, and pharmaceutical industries. The coatings provide surface hardness to 85 Rc, corrosion resistance, permanent release, and a low coefficient of friction.

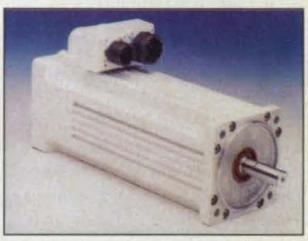
For More Information Circle No. 713

The 16AC Series **plastic gearheads** from MicroMo Electronics, Clearwater, FL, feature load-bearing values of 6N (21.6 oz.) radial and 2N (7.2 oz.) axial. The gearheads have operating temperatures from -30 to 65°C and are capable of bi-directional operation. Gearhead weights vary from .11 to .21 ounces, depending on ratio, with efficiencies to 81%.

For More Information Circle No. 716

DRS Precision Echo, Santa Clara, CA, has introduced the MTG-110 **digital tape drive** for high-speed data acquisition and video/image storage. The drive allows users to store 42 GB of uncompressed data on a single cassette, with a sustained data transfer rate of 12 MB per second over a SCSI-2 interface. It is compatible with most workstations, as well as Windows 95/NT.

For More Information Circle No. 712



The Goldline™ **brushless** servomotor from Kollmorgen Motion Technologies Group, Radford, VA, can withstand shocks of up to 40 g's and features a stainless steel shaft and rust-resistant plating and epoxy paint. Continuous stall torque from 0.62 to 80 lb-ft is available. The motor incorporates rare earth neodymium-iron-boron magnets.

For More Information Circle No. 715

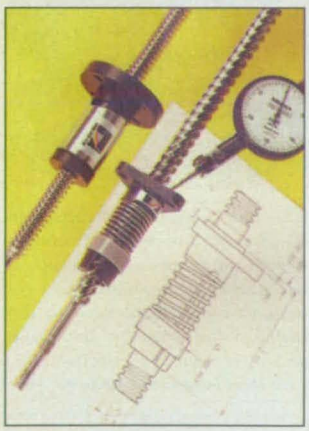
The Compaq Professional Workstation 5100 **computer workstation** from Compaq Computer Corp., Houston, TX, features dual memory controller architecture that provides 1.07 GB/second of memory bandwidth; dual-peer PCI buses; and SMP support with up to two Pentium II 266-MHz or 300-MHz processors. The workstation features host interoperability application software for operation in both Windows NT and UNIX environments.

For More Information Circle No. 711

New on the Market

The DG-525 **digital linear gauge** from Ono Sokki Technology, Addison, IL, measures dimensions, thickness, curvature, eccentricity, displacement, height, depth, flatness, variation, runout, roundness, distortion, and deflection. It measures to 0.00002" through a 25-mm measuring range. The gauge has an adjustable measuring force for taking measurements on compressible materials that require low pressure.

For More Information Circle No. 721



Ball Screws & Actuators Co., San Jose, CA, offers the XCT Supernut® and AFT Supernut® **plastic nuts** for linear positioning with zero backlash when mated with the company's stainless steel leadscrews. The XCT features the Active Cam™ Mechanism that automatically adjusts for wear; the AFT is designed for light load OEM applications up to 10 pounds.

For More Information Circle No. 710

MiTAC Industrial Corp., Fremont, CA, has introduced the MIPC-106 **industrial panel PC** with a 10.4" TFT LCD display and a NEMA 4/12 rated front panel. The Pentium-based system includes a choice of CPUs up to a Pentium 200, and an optional Ethernet connector. It features up to 128 MB of DRAM, 150W power supply, and two serial ports for RS232/422/485 interface.

For More Information Circle No. 718

Pro-Log Corp., Monterey, CA, has introduced the P7000 Pentium II **single-board computer** that features a 233-MHz CPU and support chipset, a SCSI interface, and 2-MB Flash BIOS. A floppy drive, keyboard, mouse, and LPT port also are included. Four DIMM sockets can hold up to 1 GB of synchronous DRAM. The computer conforms to the PICMG PCI-ISA standard.

For More Information Circle No. 722

The DAQMeter™ 4350 **temperature and voltage measurement instruments** from National Instruments, Austin, TX, are plug-in boards used with thermocouples, RTDs, and thermistors. Models are available for PCMCIA-based notebook computers and ISA PCs and feature five half-digit measurements, a ±15V input range, NI-DAQ™ driver software for Windows, VirtualBench™ Logger turnkey virtual instrumentation software, and an instrument driver.

For More Information Circle No. 719

Servometer Corp., Cedar Grove, NJ, offers a line of metric bellows-type **flexible shaft couplings** that feature zero backlash and can absorb parallel shaft misalignments up to 1.73 mm. They also can absorb angular misalignments to 31° and axial movements of 5.84 mm. Stock bore sizes range from 3 to 8 mm, with custom sizes available. Outside diameters range from 6.4 to 25.4 mm, with overall lengths from 12.7 to 43.5 mm.

For More Information Circle No. 723

The Vivid 700 **digitizing camera** from Minolta Corp., Ramsey, NJ, converts objects into three-dimensional coordinate data for input into a computer. The portable color scanner is a non-contact system with zoom and autofocus functions that are used to define the target object and eliminate backgrounds. An ATA-PC card enables it to operate without a workstation.

For More Information Circle No. 717

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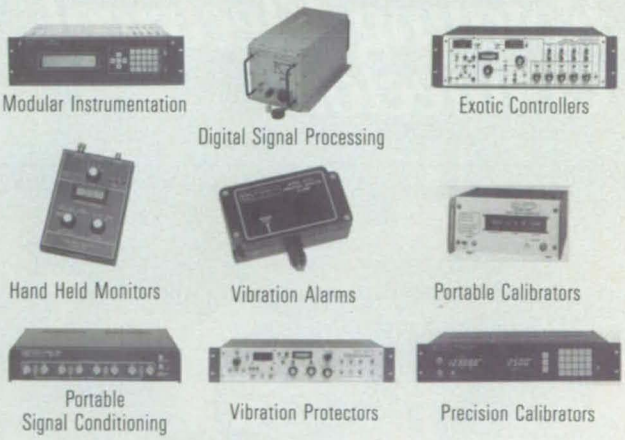

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For More Information Circle No. 447

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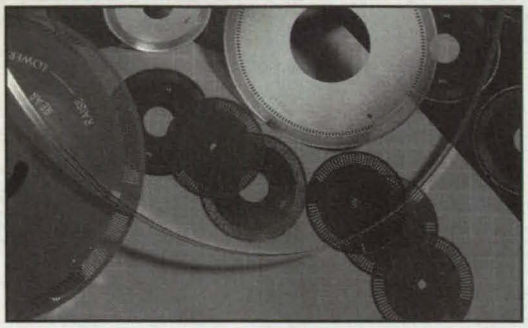

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For More Information Circle No. 448

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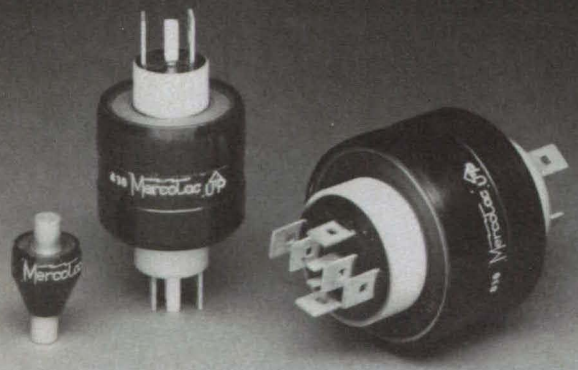

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For More Information Circle No. 449

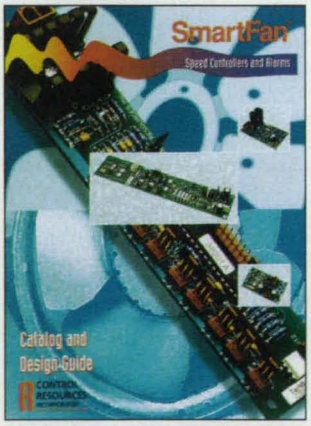
New Literature

The SC900 Series **servo drives** are described in a brochure from Pacific Scientific Automation Technology Group, Rockford, IL. Also described are serial interface, SERCOS interface, and programmable single-axis position control option cards.

For More Information Circle No. 743

GyroMax™ **speed reducers** from Shimpo Drives, Skokie, IL, are described in a 28-page catalog. Included are single- and double-reduction models, and overhung load models. The speed reducers feature the patented Circulute® tooth design for minimal contact stress.

For More Information Circle No. 741

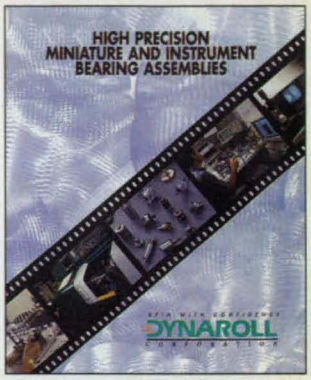


Control Resources, Littleton, MA, has released a 44-page SmartFan Catalog and Design Guide that includes SmartFan® **speed controllers and alarms** for AC or DC fans and blowers. The products are used in electronics cooling and HVAC applications.

For More Information Circle No. 742

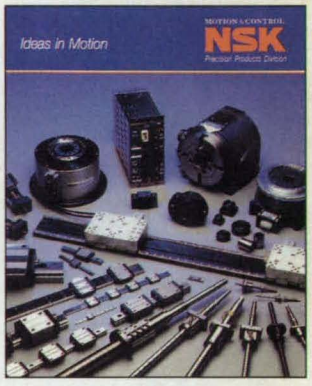
Xantrex, Bellingham, WA, offers a 48-page catalog of programmable DC **power supplies.** Rackmounts, interfaces, analog programming, and other accessories also are included.

For More Information Circle No. 740



A six-page brochure describing miniature and instrument **bearing assemblies** is available from Dynaroll Corp., San Fernando, CA. Assembly component materials include stainless steel, aluminum, brass, and bioplastics.

For More Information Circle No. 745



NSK, Bloomingdale, IL, has released a 12-page brochure describing **motion and control products** such as ball screws, linear guides, motor systems, and mechanical systems. Also included are coatings, lubricants, and other related accessories.

For More Information Circle No. 746

Indigo Systems Corp., Santa Barbara, CA, offers a brochure describing mixed-signal **VLSI circuits** available in full-custom designs. Readout devices for infrared focal-plane arrays in standard, off-the-shelf designs also are included.

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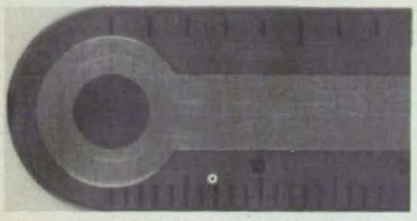

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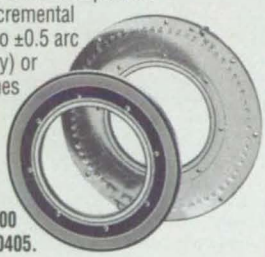

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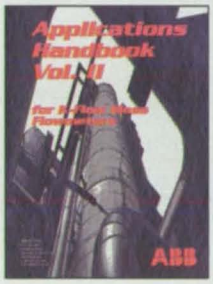

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Alesa Alusuisse Canada Ltd.		452	76
Algor, Inc.	www.algor.com	510,626,646	7,103,105
American Variseal	www.variseal.com	425	79
AMP Incorporated	www.amp.com	525	47
APD	www.algor.com/apd.htm	619,633	102,104
API Controls Inc.	www.apicontrols.com	604	101
API Portescap Inc.	www.apiportescap.com	682,603	13b,101
Applied Science Laboratories		582	111
Aremco Products, Inc.		640	104
Astro-Med, Inc.	www.astro-med.com	521	55
Autodesk, Inc.	www.autodesk.com		9-11
Automated Precision, Inc.		639	104
Barnant Company		620	102
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Buckbee-Mears St. Paul	www.bmcind.com	448	110
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Busak + Shamban		675	14b
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Carr Lane Manufacturing Co.		651	105
Chino Works America Inc.		427	82
Circuit Specialists, Inc.	www.cir.com	632	103
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Dolch Computer Systems, Inc.	www.dolch.com	512	27
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DuPont Vespel	www.dupont.com/enggplolymers	529	18-19
Eastman Kodak Company		481	3a
Edmund Scientific Co.	www.edsci.com	432, 462,616	87,13a,102
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Sumitomo Metals Industries		422	78
Sunx Sensors		570	31
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TAL Technologies, Inc.	www.taltech.com	656	105
Tec Products and Lab Services		476	10a
Tech 80 Inc.		695	15b
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Torrington, Ingersoll-Rand	www.torrington.com		13
Transducer Techniques, Inc.	www.ttloadcells.com	445,623	108,103
Trig-Tek, Inc.		447	109
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Vector Fields Inc.		631	103
Voltek, Division of Sekisui America Corporation		459	90
Watlow Gordon	www.watlow.com	545	29
Wescon-IC Expo/97	www.wescon.com	532	106
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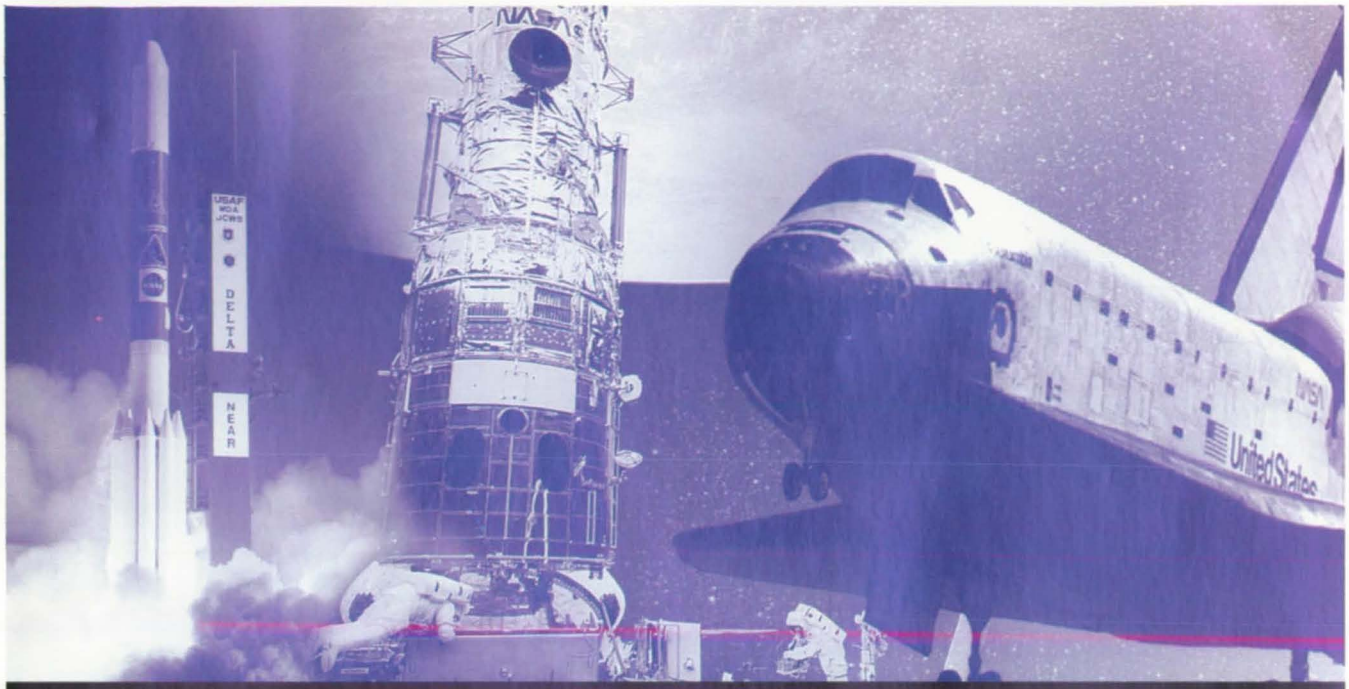
Working Model, Inc., Div. of Knowledge Revolution	www.workingmodel.com	523	63



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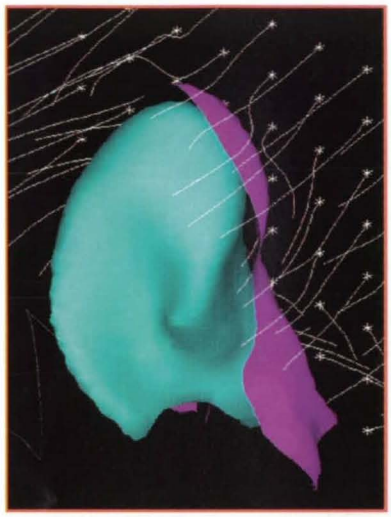

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